



AN ENGINEER'S OUTLOOK

BY

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K.C.B., F.R.S.

WITH A PORTRAIT AND 5 DIAGRAMS



METHUEN & CO. LTD.
36 ESSEX STREET W.C.
LONDON

First Published in 1933

PRINTED IN GREAT BRITAIN

TO

E. L. E.

WISE CRITIC AND DEAREST COMRADE

P R E F A C E

WHEN my friend E. V. Lucas undertook that his firm should publish this volume of collected papers and addresses, he remarked, with the pregnant brevity that helps to make his talk delightful : 'It will be your monument'.

In that spirit I venture to write this preface as a brief biography and to begin it by saying that I was born on March 27, 1855, in Dundee, where my father was a minister of what was then called the Free Church of Scotland. He had been chosen at an early age to be minister of a parish in that thriving industrial town, but had 'come out' in the Disruption of 1843, when the Church of Scotland was rent in twain on a question of spiritual liberty. His people, who were already devoted to their young pastor, had nearly all come out with him. They built a new church, in which the Sundays of my boyhood—morning and afternoon 'diets'—were mainly spent. It was a simple, capacious temple with a dignity that fitted the customary Presbyterian rites. Happily, after many years, the breach of 1843 has been healed : the Church of Scotland (save for a few die-hards) is again a united whole. In Scotland it is Episcopalians who are dissenters. (I liked to remind Bishops of that when they came to Edinburgh to receive honorary doctorates of divinity.) In those days, however, besides the weakness of disunion, there was still some of the soreness of recent controversy ; there was a sense on the part of those who had come into the wilderness that they had left behind them such loaves and fishes as the Church could offer its disciples. They consoled themselves by reflecting, truly

enough, that they had run grave risks and made great sacrifices in pursuit of a high ideal. Their coming out had in fact given a new impulse to the spiritual life of Scotland.

The ministerial household was an entirely happy one, with no straining of bonds, no restrictive narrowness, but with abundant opportunities for intellectual and spiritual growth. I dare say it might seem 'stuffy' to the modern young. To me it was never irksome, nor was there any reaction when adult independence supervened. I cannot be too grateful for its gentle leading and constant light. The phrase 'a refined home' may sound banal; it describes what to me was a potent reality and is still a beloved memory.

My father came of sturdy farmer stock, a man of superb physique, of whom a friend said that a good cavalry officer had been spoilt to make a minister. He had gone to the University of Glasgow at what seems now an incredibly early age, and soon after completing his courses there in Arts and Divinity had been called to the charge of a Dundee parish. I believe it is literally true that he never missed a day's duty through illness, nor shirked one for any reason. No worries ever seemed to ruffle him. His burden, however, as minister of a great congregation was heavy. It was natural that the care of the children should fall almost wholly on their mother: she was the radiating centre of the family life. In some marvellous way she contrived to be our teacher, no less than the universal provider of what was needed by body and by soul. It was to her that my brothers and I owed nearly all our early education. She gave us much of what other boys got at school, and did it in a way that made us associate a love of learning with our love of her.

Eldest daughter of a Glasgow solicitor with a large family, she had a naturally sound critical taste in letters,

which had been developed by a more liberal education than girls of that period commonly enjoyed. Though no blue-stocking, she had sought the kind of culture which books give, and she passed the enjoyment of it on to her children. Long after her fledglings left the nest she maintained a communion with each of them by weekly letters, covering many pages in the fine Italian hand which educated women then favoured—fresh, spontaneous outpourings not simply of domestic news, but of a spirit that was steadily serene, humorous, sympathetic, interested, and always interesting.

My father, who died in harness while making a pastoral visit, held for nearly fifty years the affection of a big congregation. One may say, with no exaggeration, that in a less intimate fashion he won and kept the unqualified esteem of the whole city. His sane judgment, his unstudied goodwill, his transparent sincerity made many friends. To us boys he had a quality perhaps rare in Victorian fathers—a quality which we thought very estimable: he treated each of us as a person whose individuality deserved and should receive respect.

Somehow or other, on a stipend that was meagre even in those days (it never exceeded £400), he contrived that each of his three boys should receive a university education. We helped, of course, by some winning of scholarships, but even so it must have been a strain. The eldest, Robert, went first to St. Andrews and then to Balliol. He became a college don, migrating to St. John's to take a fellowship, a tutorship, and afterwards a college living at Winterslow, which he soon exchanged for one in the town of Trowbridge, because that offered a welcome opportunity of much harder service. He died, far too early, an Honorary Canon of Salisbury—on his way, I fancy, towards higher office in the Church. There is still a tradition among old Oxford men of the unlimited

activity and distressing efficiency of 'Bobby' Ewing as a proctor. In any case he never spared himself, and became, it would seem, a victim of his insatiable appetite for work. There was an unflagging quality about his energy which his younger brothers, though they were by no means lazy, could only admire but not hope to rival. As with his father, death came suddenly while he was making a pastoral call.

The second brother, John, was of a more contemplative type, with a touch of genius that set him apart from the rest of us. He, too, went to St. Andrews for his course in Arts, and then to Edinburgh for his theology before being ordained as a Presbyterian minister. In the 'New College' there he was one of a little group whose combination of liberal thinking with ethical and religious fervour left a deep mark on the life and mind of Scotland. His preaching held the ear through its literary finish, its imagination, its incisiveness, and its ardour. After clerical experience in Dundee and Glasgow he was called to the church of Toorak in Melbourne, where his quality was at once recognized. He became a leader whose influence is still a living tradition among old Australians. What promised to be a brilliant career was cut short by typhoid in 1890, when he was only forty-one.

To John, who was my senior by about six years, I owed much shaping of character. His talks about books, poetry, metaphysics, religion, his undergraduate enthusiasms and his post-graduate convictions, his pungency and wit, the simple directness of his Christian ethic—all these meant illumination and guidance to a receptive boy.

He tried, among other good things, to make me love mountain climbing, for which he had the passionate fondness of the expert. But for me (indeed sometimes even for his guides) the pace was far too hot; the burden of it

was greater than I could bear. As a young man it definitely put me off. It was not till middle life that I discovered for myself how modestly joyous it is possible to be upon the mountains when one may not only choose and see one's path but determine the rate of progress.

The only living sister, junior to me by a good many years, counted for little to the growing boy but much indeed later to the man—and to his progeny. She, too, shared the predilections of the rest : she married a clergyman, who taught her, in maturity, to appreciate Homer as well as the Gospel of Saint John in the original text. The substance of that Gospel was already woven into her life through the influence and example of our mother. But in the education of my sister school counted for more than it had done with the boys, for by that time our mother's philanthropic instinct had begun to find other outlets and wider exercise, bringing claims that interfered with tutoring at home.

In a family whose chief interests were clerical and literary I was a 'sport' who took his pleasure in machines and experiments. My scanty pocket-money was spent on tools and chemicals. The domestic attic was put at my disposal. It became the scene of hair-raising and hair-singeing explosions. There, too, the domestic cat found herself an unwilling instrument of electrification and partner in various shocking experiences. Fortunately perhaps for me, but little science was then taught at school, and that little so badly that a boy whose bent was scientific found means to learn for his own pleasure what would otherwise have been a task. It was in this irregular fashion that I began to explore the pleasant borderland of physics and engineering where I have roamed happily for many years.

In another place the story is told of my mother's taking me to sit for a few hours very prematurely at the

feet of a great master when the British Association first visited Dundee.

In due time I proceeded to the University of Edinburgh, first holder of an engineering scholarship in the gift of the Dundee High School, and became a serious—a very serious—student of engineering. The Professor was Fleeming Jenkin, an inspiring teacher, of whose many gifts and personal kindness something is said in this book. To him, and to his wife, I came to owe far more than an introduction to technical study: to know them was in many ways an enrichment of life.

In those days the session of a Scottish University was crowded into six months, so that a needy undergraduate (and nearly all of us were that) might spend the other six in replenishing, by means of some paid employment, the bag of oatmeal which enabled him to cultivate the muses. Cynics were not wanting who dared to suggest that the arrangement found favour for another reason: it secured to our teachers an agreeably protracted period of undisturbed contemplation. With Jenkin the long vacation meant professional business. At the end of my first session he told me that he and Sir William Thomson (afterwards Lord Kelvin), who were partners in the engineering of submarine telegraph cables, wanted additional staff. If I cared to become one of their assistants he would send me to a London cable-factory for the summer and let me resume study in Edinburgh in the winter. To a youngster without money or professional influence such an offer opened vistas: it was the beginning of a connection which grew intimate and set me, professionally, on my feet.

It gave me, too, a chance to see something of the world in three cable-laying voyages to Brazil and the River Plate, where, incidentally, I had the thrill of witnessing a revolution in the Republic of Uruguay.

Later, on Jenkin's nomination, I went to Japan as a very young Professor of Mechanical Engineering in the University of Tokyo, and there I spent five educative years, from 1878 to 1883.

The Japan of those days was venerable in its traditions, its literature, its art, its manners, its high standards of patriotism and of personal duty. It was almost painfully young in the veneer of western culture which it had begun eagerly to acquire. To an inexperienced teacher there was stimulus and help in pupils whose polite acceptance of everything he put before them was no less remarkable than their quick intelligence and receptiveness. They were tolerant, they were apt, most of them were personally attractive. For quite half a century two or three of these Japanese youths of 1880 have kept in touch with me as a friend.

A few, too, were responsive in developing a passion for research. In the later years of my employment the Japanese authorities extended my functions by getting me to undertake some teaching of physics; and with the help of a group of the best pupils I began experiments in magnetism, which they took up with an enthusiasm that left nothing to be desired. It is pleasant to know that there is still an active school of magnetic science in Japan. Some aspects of that study are dealt with in a lecture which will be found reprinted here. The experiments we made together had this special interest that they dealt with points which almost immediately became important through the rapid development of electrical engineering, then in its infancy.

For myself, the attractions of research had been strong from the time a first impulse in that direction was given in the laboratory of Professor Tait, who was my earliest teacher of physics. Those were the days when Thomson and Tait were giving a new formulation to what in

Scotland we still call 'Natural Philosophy'. It was the happiest of accidents to be brought also under the personal influence of Sir William Thomson. In one of the papers of this volume I have tried to say something about that very great man and about a little section of his work. While with Jenkin I also had more opportunities for research than usually fall to the lot of a young assistant. There was an exhaustive examination of a novel type of internal-combustion engine which had every merit except that it would not go. There were experiments on the harmonic analysis of vowel sounds, in which we turned Edison's newly invented tinfoil phonograph to scientific account. When I went to Japan I took one with me : its capacity to speak Japanese with a slightly nasal twang was a double passport to popularity. There was also, on my part, an instant attraction to earthquakes as a subject of experimental study, and no little satisfaction in devising instruments which would make the earthquake itself write, if not the story of its birth, at least a complete account of the components of its motion, in all phases of the disturbance from start to finish.

Much later, when I became a Professor at Cambridge, I was happy in finding pupils who co-operated in researches on the crystalline structure of metals and in discovering how an aggregate of crystals—such as we find in every metal—can exhibit plasticity through the slipping processes that occur between atomic layers. The slips were made manifest by the appearance of fine lines on a polished surface, when the metal was sufficiently strained to undergo a permanent alteration of form. It was a new departure in a field of inquiry which soon attracted many workers.

But there is no use of wearying the reader with technical particulars. This book is not a catalogue, still less a reprint, of scientific papers. For these, if one wants them,

one must go to the dusty shelves where 'Philosophical Transactions' and 'Proceedings' of learned societies are stored. The interest of such papers, so far as they have any, soon becomes mainly historical. At the best they chronicle stages by which science has risen on stepping-stones of its dead self to positions that command a wider view—positions which, for the most part, are left behind as the ceaseless advance proceeds.

To come back to more personal matters. The Tokyo of 1878 provided a cosmopolitan society of diplomatists, official advisers, teachers, missionaries, and their respective wives—pleasant, polyglot, and piquant. I had not been many months there before a swift courtship was successful, and I married the step-daughter of a fellow-professor. She was a Miss Washington, a great-great-grandniece of the famous George—one of a family which had kept the English colonial tradition of feeling and manners and conduct unimpaired. Her childhood had been spent in a country mansion of West Virginia with an entourage of devoted and apparently quite contented slaves. The family fortunes had suffered sadly in the American Civil War, but nothing could affect her heritage of well-bred charm. Before she died she had the joy of seeing the two babies whom we brought home from Japan reach man's and woman's estate, to the entire satisfaction of us both.

My second wife was a daughter of John Hopkinson, F.R.S., Senior Wrangler and First Smith's Prizeman, twice President of the Institution of Electrical Engineers, inventor, pioneer, and accepted leader in the applications of electricity to the needs of man. He, too, had done early experimental work in magnetism, and this brought us together, forming the basis of what soon became a close family friendship. The tragedy of his death in the Alps in 1898 when he and three of his children

were killed by a fall while climbing the Petite Dent de Veisivi, drew us closer to what remained of the family, and later the only surviving daughter became my wife. It is through her that I find the evening of life to be, in quiet happiness, the best part of the day.

When I went to Japan in 1878 it was under an engagement to serve as Professor for three years. At the end of that time the Japanese authorities asked me to stay, and I did so for two years more. Then they wished me to stay longer ; but pleasant though the service was in every way, it did not seem to offer a career, and I decided to take the chance of getting work at home. The chance came, before I left Tokyo, in my appointment as Professor of Engineering in a University College then about to be established in my native town. There I had seven years of further experience in teaching and research, and gained some little knowledge of civic life by service on the School Board and in other ways. The new University College was the pet of many kind people in that big community ; they gave the group of young professors a more than cordial welcome, as a novel feature in the town's social life. After a rather long novitiate the College became an integral part of the oldest of Scottish Universities—St. Andrews, which could already boast a history of nearly five hundred years.

In 1890 the Professorship of 'Mechanism and Applied Mechanics' at Cambridge fell vacant through the resignation of the late Professor James Stuart, who had been its first holder, and for whom, indeed, the Professorship had been created. He was a zealous promoter of University extension, and had striven to temper the severity of Cambridge mathematics by showing that it had applications to practical affairs. He had established workshops, where undergraduates might learn something of the use of tools. But after a time, politics and journalism had

diverted a large part of his attention from missionary effort in engineering : the workshop venture had fallen into some disfavour, and when he resigned the Professorship it was said that the University would have been glad to drop the whole thing, had that been possible. Fortunately for me it was not. On the advice of John Hopkinson I offered myself as a candidate and (doubtless also on his advice) I was accepted. I was a stranger, but Cambridge took me in with a dispassionate readiness which was as gratifying as it was surprising. Soon the department acquired a laboratory, through the generosity of donors, and a *Tripos*, through the large-mindedness of the University. It flourished exceedingly ; the number of students increased at an embarrassing rate. A much needed addition of space was provided in 1899 when a wing was built in memory of John Hopkinson, the gift of his widow and surviving children. When I left it in 1903 it was already the nucleus of a big school. My successor was Bertram Hopkinson, F.R.S., the eldest son of John ; in his reign the growth continued and the reputation of the school both for teaching and research was much enhanced. Near the end of the war, to the grave loss of science, he was killed, while flying : the Professorship then passed to its present holder, Charles Inglis, F.R.S., who had been my pupil. In his able hands the school developed so overwhelming a post-war activity as to need removal to far more ample quarters. A great new laboratory has been built, and the numbers are now larger than those of any other English engineering school.

From the Cambridge Professorship I was uprooted, very unexpectedly, in 1903. The Admiralty were about to introduce what was called the new Scheme of Naval Education. Lord Selborne, then First Lord, who with the late Lord Fisher (then Sir John) was promoting the scheme, asked me to come and advise about some of the

details, telling me that the general idea was to infuse a large element of engineering knowledge into the training of every naval officer. I went up and discussed the scheme with him and Fisher : it was my first vision of that volcanic personality whom, later, I was to see often both in quiescence and in eruption, and to learn something of his greatness. If I was observing them they, apparently, were observing me ; for a few days later Lord Selborne wrote again, offering, on very generous terms, an appointment as Director of Naval Education : it was to be a new office, created as an adjunct to the new scheme.

This meant an entire change of life and of obligations. It meant giving up research as well as teaching, and also dropping a considerable professional practice, especially in the Law Courts, where I found that to appear from time to time as an expert witness was pleasantly remunerative as well as excellent sport. After hesitation I decided to suffer a sea change into something which, if strange, was definitely less rich—and became a civil servant of the Admiralty.

A government office, even when entered under conditions so favourable, stood in sharp contrast to the Cambridge freedom, where I could do whatever seemed right in my own eyes without so much as a syndicate to be conciliated or to say me nay. With members of the Board of Admiralty I had always the happiest relations : among those below them one was sometimes conscious of cross-currents. Whitehall is a useful school of tact, especially perhaps for one who comes in by a side door and has not climbed the ladder on the usual rungs. At the outset I was warned by an old hand that I should find in the Admiralty three streams of tendency (he called it a triangular duel, but that is too harsh a phrase) : these were the secretariat, the naval men, and the civilian

experts. My job gave me much agreeable association with all three, in the office, and with many other naval men at the ports, and in the Fleet.

When the war came, any cross-currents—for a time at least—were merged. All were swept into one stream of effort : even the Treasury lost its customary control.

The war brought me a wonderful piece of good fortune. When it began I was asked if I would undertake to deal with enemy cipher, a matter for which no pre-war provision had been made. Except for an amateurish interest in methods of ciphering, I had no special fitness, but I could not refuse to try. This led to the creation of a department which came to be known as Room 40. Its operations were kept—as was essential—very strictly secret. Their success was due in part to luck, but chiefly to the skill and devotion of members of an extemporized staff who were gradually brought together. To me the building up and charge of Room 40 was the most interesting episode in a life that has never lacked variety, and one feels still that it was work of real consequence.

That charge came to an end in the summer of 1917 when I handed over Room 40 as a going concern to Admiral Sir Reginald Hall, who was Director of the Intelligence Division of the War Staff. I had been invited, very unexpectedly, to become Principal and Vice-Chancellor of the University of Edinburgh, and Lord Balfour, who as First Lord knew all about Room 40, and as Chancellor knew the needs of the University, advised me to accept the office, suggesting, however, that my charge of Room 40 should continue. That arrangement was in fact maintained for about a year, until the claims of Edinburgh grew too insistent to make the double duty practicable or desirable.

When my wife and I went to Edinburgh we found the University stagnant under the shadow of the war, depleted

of students, struggling with difficulties of finance, and about to struggle with big problems of reconstruction. Such problems quickly became urgent when the University was almost submerged by the returning tide.

The Principal of a Scottish University is effective in proportion as his Court and his Senatus back him up. I was happy in having the support of both bodies during thirteen very strenuous years. Doubtless the experience of a government office had its uses in making me less unfit to guide others than I should have been without that discipline. I was fortunate, too, in finding large-hearted donors with gratifying confidence and well-filled purses. A Principal has to echo the daughters of the horse-leech : he is specially grateful when—as rarely happens—the money is given unsought. In the spending of it he has to weigh needs and balance conflicting claims. It was an immensely interesting life, in its contacts with undergraduates, with colleagues, with the city, and with distinguished strangers. The social side was particularly important : there my wife was leader and played an invaluable part. It was a constant strain upon us both, and it became wearing to a man who had passed the age-limit of the Psalmist. So I did well, for the University's sake and for my own, to retire in 1929 when small ailments began to sound a warning note. It was consoling to find other people profess themselves unaware that the time had come for me to go : consoling also that when the strain was relieved the ailments disappeared.

We quitted Edinburgh—and a host of friends—with much regret, but with a clear sense that the retiring vicar ought to leave the parish. To return to Cambridge was to come home, and to find, after many years, less change than afflicts most parts of this quickly changing world. Cambridge did not ask the wanderer why he had ever gone away : it only brought forth a scarlet robe, and college

kitchens continue to furnish the appropriate veal. In Cambridge one's lines fall in pleasant places. For an honorary fellow of a College there is much privilege and scarcely a trace of responsibility. And in the Chapel of King's one realizes, as perhaps nowhere else with so compelling a force, the value of beauty as a handmaid to religion.

Among the many merits of this delectable town is its nearness to London, a special merit for one who seems to be not yet too old for conferences and committees. The Department of Scientific and Industrial Research (I wish it had a shorter name) has a long arm : it draws in a surprising amount of unpaid expert service. For a veteran who recognizes that his earning days are over this is all very well—his misgivings as to age are lulled—he is happy to be deemed useful—but I often wonder that so much time is generously spent by men who are at the summit of their professional powers or beset by business claims. To sit with them at Boards which are not in the least festive is exhilarating : it keeps the veteran informed and more or less alert, especially when it is his duty to take the chair.

And now a few words about the contents of this volume.

The first paper was my address as President of the British Association at the York meeting last year. It is an *olla-podrida* of reminiscence and exposition and reflection. Its title, 'An Engineer's Outlook'—which serves also as a title for the book—must not be interpreted as a claim on my part to be, or ever to have been, in any full sense an engineer. Engineers build their monuments in steel or stone : I have never done that. But I was for long a teacher of engineers in the science of their art ; I can point to a host of old pupils who have won more than their spurs—some of them have won their knight-

hoods. I have expounded the subject in books, have carried out researches, and served on many engineering councils and committees. So I have learnt to look at the world through engineering spectacles, to watch the development of engineering ideas and habits, and to trace some of their consequences. It is in that sense that the phrase is to be understood.

The British Association does not often select a President whose interests are mainly engineering. It seemed fitting to put into words what must already have been in many men's minds, that the gifts of the engineer to mankind are good gifts only if they are used with wisdom : that they carry dangers of more than one kind—among them the danger of excessive leisure through the mechanization of industrial life.

The second paper was an address to the Institution of Civil Engineers on the occasion of its centenary in 1927. It passes in quick review a long pageant of discovery and invention. There, too, the final pages strike a warning note on the suicidal tendency of international mistrust.

The next two papers deal with Power: one of them was a lecture, given at the centenary meeting of the British Association, in discharge of a Trust of the late Sir Frederick Bramwell, that the Association should discuss his prophecy, made fifty years before, that the internal-combustion engine would displace steam in the production of motive power.

After that comes an earlier address on Magnetism, which was then, or had lately been, my chief subject of research : and to that a note is appended, from a recent discussion by the Physical Society, which illustrates how far the subject has travelled since those days.

Then comes a memorial lecture on the work of Lord Kelvin in Telegraphy and Navigation—which deals with

two minor sections in the gigantic achievement of that scientific pioneer.

Next is an obituary estimate of the late Sir Charles Parsons, whose invention of the steam turbine has revolutionized steam engineering. I had watched the work closely in the beginnings of its success : I had a warm friendship for Parsons and intense admiration of his courage, insight, and resource, and so the tribute was paid from a full heart.

The other essays are more general. An address on 'The Universities and the New Era' marks the commencement of my Edinburgh Principalship ; it has some addenda—extracts from later ex-cathedra pronouncements. A Lay Sermon follows, which may be said to mark the end of that period. It was delivered to the students, in the Cathedral Church of St. Giles, by request of my clerical colleagues, soon after I had retired.

The paper which comes next, on 'The Fleeming Jenkins and Robert Louis Stevenson,' tells of youthful days in Edinburgh, reviewed by one looking back after more than half a century. It was written for Miss Rosaline Masson's volume entitled *I Can Remember Robert Louis Stevenson*. I am grateful to her (and to the publishers, Messrs. W. & R. Chambers) for leave to reprint it, and also to her sister, Miss Flora Masson, for letting me include her narrative of one of the episodes, as seen from the other side of the curtain.

Then come various odds and ends, speeches and fragments that tell their own story, such as it is. After them is a note on the late Lord Balfour, which the publishers of *Nature* kindly allow me to reprint. It mentions various occasions when Lord Balfour delighted us with his presence in Edinburgh as Chancellor of the University. At one of these academic functions he made a public speech, reported in the *Scotsman* of November 7,

1925, about the war work of Room 40, and disclosed my connection with it. He did this, he said, because 'his tongue was untied upon that secret subject' through the (then recent) publication of letters written by the late Mr. W. H. Page, who had been American Ambassador in England during the war, and 'what was a secret had now become public property'.

I had hoped to include in this volume a short account of that work, but official permission to print it has been withheld. From the historical point of view this seems regrettable. The story has enough value to deserve authentic telling.

The last chapter is a recent Hibbert Lecture on 'Science and some Modern Problems', which treats of certain difficulties the world has to face in consequence of continued advances in discovery and invention.

The photograph is by the late Mr. Swan Watson of Edinburgh, a real artist of the camera who knew how to make the best of unpromising material.

I would thank various bodies and persons for allowing papers to be reprinted—the Royal Society, the Institution of Civil Engineers, the Institution of Electrical Engineers, the Physical Society, the Institute of Physics, and others already named. In editing papers for reprinting I have not hesitated to make changes where it seemed desirable.

So much for autobiography. To write it is like picking one's way over marshy ground : a false step, and one may be ankle-deep in egotism. Now, with mingled relief and doubt, I look back to the first paragraph of this preface. *Si monumentum requiris* (though why should you ?)—here it is.

J. A. EWING

CAMBRIDGE, February 1933

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AN ENGINEER'S OUTLOOK

BEING THE PRESIDENTIAL ADDRESS TO THE BRITISH
ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,
AT YORK, 1932

I

AGAIN, for the fifth time, the British Association meets in York, a city of proved hospitality and the stage of great events. York is a monument of history ; its very stones are eloquent of the past. Not the least of the episodes it has witnessed was the birth of this Association. Your city, my Lord Mayor, was our cradle : we hold York in filial honour and affection. We are nomads who have strayed to the ends of the earth : we have been as far-flung as the British flag. We have enjoyed the welcome of many strange hearths. But here there is nothing unfamiliar. We take delight in coming home to a birthplace of happy memory and in recalling hopes which the past hundred years have generously fulfilled.

Last year the infant of 1831 celebrated its centenary in the vigour of manhood, with a plenitude of pomp and circumstance which demanded no less ample a setting than the metropolis of the Empire. For President we had a man of world-wide fame, who fittingly embodied the imperial aspect that is part of the glory of the British Association. We had long known General Smuts as soldier and statesman : to some it may have come as a

A

surprise when they found him also a philosopher, a student of ideas no less than a maker of history and a leader of men. It would be an impertinence for any successor in this chair to praise General Smuts ; to follow him is perforce to follow far behind. But one may congratulate the executive on the happy instinct which recognized that the occasion was unique, and so led them to an unusual—not to say a daring—choice. It was amply justified by the event. Now they have returned to the beaten track along which Presidents for the most part plod, and have made a selection for which I am glad to have no responsibility.

Of General Smuts I would say one word more. His occupancy of the chair not only added to the lustre of our rejoicings : I like to think it had a deeper significance. May we not regard it as a harbinger of the spirit of goodwill and sanity which civilization longs for, but does not yet see ? One hundred years of science have done sadly little towards curing the nations of mutual mistrust. Surely it was a good omen that, in marking the close of one century of achievement and the opening of another, we should have had for President a citizen of the world whose life has been a lesson in subordinating the lower patriotism to the higher good, who by example no less than by precept has taught his fellows that they should beat their swords into ploughshares and not learn war any more.

Now we revisit our birthplace well aware of our maturity. We have scored our first century and begun to compile our second with the easy assurance of a Bradman or a Hobbs. At once the question arises, Is that assurance justified by the Association's continued vitality ? Do we still give the community reason to support us ? Or are we a survival, trading on a reputation which our present activities do little to increase ?

I put the question bluntly—nowadays we are all familiar with disagreeable stock-takings and shrinking values—but it need not detain us long. I am confident you will find no trace of decrepitude. It is true that the sciences included in our purview have become specialized and differentiated to a degree that would make ridiculous any claim to the qualified omniscience which was possible in our early days. It is also true that each department of science now has its own society of votaries who meet as it were in a masonic temple and converse in a jargon that has little if any meaning for the general ear. But these very facts make this Association the more useful. Notwithstanding the restrictions of specialism, science has its own broad outlook, demanding expression and explanation to laymen. And more than ever is it true—far truer than it was a hundred years ago, when we were ridiculed as a hodge-podge of philosophers and made the target of an unsympathetic Press—that laymen want to have intelligent contact with the seekings and findings of the scientific mind.

I say seekings and findings rather than conclusions, for that word has too final a ring. Here we may note a striking change in the temper of the investigator. I am old enough to remember a time when some of the spokesmen of science (never, indeed, the greatest) displayed a cocksureness that is curiously out of keeping with the spirit of to-day. Among contemporary leaders nothing is more general than the frank admission that they are groping in a half-light, tentatively grasping what at best are only half-truths. Things that to one generation seemed to be essential parts of a permanent structure are treated by the next as mere scaffolding. The quest of truth goes on endlessly, ardently, fruitfully. And yet with every gain of knowledge we realize more clearly that we can never really know. To understand, as Ein-

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stein lately said, is to draw one incomprehensible out of another incomprehensible. From time to time we discover a fresh relation between observed phenomena, but each of the things which are found to be related continues to evade our full comprehension ; and that is apparently the only kind of discovery we can achieve. Our joy in the quest itself never fails ; we are constantly learning that it is better to travel than to arrive.

The philosophical implications of this altered attitude are many—indeed they concern the deepest springs of thought. What I wish at the moment to point out is that the new spirit strengthens a sense of brotherhood between the scientific adept and the average man, who in his own way is also commonly a seeker after truth. He listens gladly when the specialist drops his toga and admits that in scientific matters the only dogma is that there is no dogma. Obviously too the advance of science makes an increasing claim upon the layman's notice through its technical applications. It invades his home and alters his ways ; it affects almost every feature of the daily round ; it brings him interests, comforts, wealth ; it enormously enlarges his powers of work and play. And, further, at a time like the present, when we carry a load of social and political and economic discontents, the ordinary citizen doubtless reflects that if only we could apply the dispassionate temper of science to the difficulties of the hour we might face them with less waste of effort and greater likelihood of settlement.

These are a few of the reasons why the British Association keeps its hold on the public. It links experts with one another and with laymen, to the benefit of all. Experts gain by indulging in a short interval of comparatively lucid self-expression. They gain also by trying to understand each other, which is by no means so easy as you might suppose. To meet under these happy

conditions is a stimulus to everybody. An old worker in science looks gratefully back on his attendances at the British Association not only as delightful human events but as red-letter days in his own development, as milestones in the unceasing march of his subject, and as helps in the hard task of keeping himself more or less in step.

It is recorded that York was chosen for our birthplace because in the Yorkshire Philosophical Society the infant would secure intelligent dry-nursing at the hands of a large body of friendly amateurs. In a letter to the Secretary of that Society, Sir David Brewster described the purpose of the proposed Association in the following words :¹

'The principal objects would be to make the cultivators of science acquainted with each other, to stimulate one another to new exertions, to bring the objects of science more before the public eye, and to take measures for advancing its interests and accelerating its progress.'

There, in a nutshell, is what the Association set out to do, what it may fairly claim to have done, and what it still does. If you want an illustration, you had it last year when a great audience sat for hours, with every sign of sustained attention, while the Evolution of the Universe was discussed by British and foreign specialists of acknowledged authority, immense learning, and conspicuous variety of opinion.

At the end of that symposium the debate was admirably summed up by Sir Oliver Lodge, the Nestor of physics, who in every sense has filled a big place in our gatherings for more than fifty years. In a recent volume of reminiscences² he tells delightfully of the meetings

¹ *The British Association : A Retrospect, 1831-1931*, by O. J. R. Howarth, p. 14.

² *Advancing Science, being Personal Reminiscences of the British Association in the Nineteenth Century*, by Sir Oliver Lodge.

ever seemingly inert, is mighty in being a magazine of energy which, for the most part, it locks safely away. This is fortunate, for if the secret were discovered of letting loose the atomic store we should invite dissolution at the hands of any fool or knave. And it is also fortunate that in the furnace of the sun, at temperatures far higher than those of our hottest terrestrial infernos, the stored energy of the atom is drawn upon, as we believe, and has been drawn upon for ages, to keep up that blessed radiation which makes man's life possible and is the source of all his power.

In the middle nineties there set in an astonishing renaissance of physical science which has centred in the study of the atom and extends by inevitable logic to the stars. In quick succession came three great discoveries : the X-rays by Röntgen in 1895, radio-activity by Becquerel in 1896, and the electron by J. J. Thomson in 1897. Sensational, puzzling, upsetting, these events inspired every physicist to new activities of thought and equipped every laboratory with no less novel methods of research. A flood of further discovery followed, the flow of which continues unabated. Within the last few months notable items have been announced that well deserve our attention. It may not be inappropriate if I try for a few minutes to touch—however lightly—on one or two aspects of this subject, as it is seen through the eyes of an engineer.

Thanks mainly to J. J. Thomson, Rutherford, and Bohr, we now recognize the atom of any substance to be a highly complex structure, built up, so to speak, of two sorts of blocks or brick-bats—the electrons, which are indivisible units of negative electricity, and the protons, which are indivisible units of positive electricity. It is strangely simple to be taken back, as it were, to the nursery floor and the childish game, and given just

two sorts of blocks, exactly alike in each sort, and exactly the same number of each sort, with which to build the universe of material things. The blocks are unbreakable : we cannot produce them or destroy them or change them. In respect of electrical quality the two kinds are equal and opposite, but they contribute very unequally to the atom's mass, each proton (for some reason not yet understood) contributing about 1840 times more than each electron. Every substance is made up of blocks of the same two sorts. If you compare different substances you find that the diversity of their chemical and other properties arises solely from differences in the number and arrangement of the blocks which compose their atoms. Any atom, in its normal or electrically neutral state, must contain an equal number of protons and electrons. All the protons in any atom are gathered close together at the centre, along with some of the electrons, forming a compact, dense portion which is called the nucleus. Although the nucleus accounts for nearly the whole of the atom's mass, it occupies no more than a very minute fraction of the atom's volume. Those of the electrons which are within the nucleus doubtless serve to bind the protons together ; the other electrons constitute, as it were, a voluminous crinoline, or rather a series of crinolines, extending relatively far away from the centre and giving the whole atom an exceedingly open structure. Within that open structure upheavals may be caused by outside agents in various ways. One or more of the electrons in the crinoline may be temporarily removed (as, for instance, by the action of heat or by the incidence of energetic radiation), and the atom is then said to be ionized : for a time the balance between positive and negative is upset. But the missing electron returns to its place, or another comes instead, and when this happens a definite amount of radiation is given out, much as

he has frequented and the friendships to which they have led. If he is thankful for them, so are we for him. Not a few of us have found inspiration in the fountain of his knowledge, in the spontaneity and aptness of his spoken word, in the width of his sympathy and understanding, and have learnt to love him for his large humanity.

My own first contact with these meetings antedates even that of Sir Oliver. Sixty-five years ago it chanced that the Association in its peripatetic course came, for the first time, to my native town, and I was taken, a boy of twelve, by my mother to the Section of Mechanical Science, having already announced my intention of becoming an engineer. To the pundits of Section G we must have seemed an odd pair, the douce minister's wife and the shy little boy in his kilt. It was by my own wish, of course, that I was taken, and my mother counted no labour lost that might develop intelligence in her family of sons. The boy could not understand much of what he heard ; it was something, however, to see the leonine head of the sectional president, Macquorn Rankine, over whose engineering text-books he was later to spend many assiduous hours. There is no boundary to a mother's dreams, but in their wildest excursion they can scarcely then have pictured what is happening in this hall to-night.

Here let me make a confession which may also serve as an apology. I have the unwelcome distinction of being the oldest President the Association has ever suffered. In its primitive years the average age of Presidents scarcely exceeded fifty : one of them, aged only twenty-nine, afterwards founded the Cavendish Laboratory, and so did a service to science which it would be impossible to over-value. As time went on the choice fell on older men, and now the electors have taken what one hopes may be regarded as an extreme step. But, as it happens, this is

not the first time I have read the President's Address. At the Edinburgh meeting of 1921 the President, Sir Edward Thorpe, was prostrated by illness and asked me to act as his mouthpiece. The small service so rendered brought an unexpected reward. Some newspaper report must have confused the platform substitute with the real President, for a well-known novelist sent me a copy of one of her romances which was no doubt meant as a tribute to Sir Edward. It was called *The Mighty Atom* —an arresting title. Perhaps that is why I did not read beyond the title-page. Without close examination it was put by a more orderly hand than mine on a shelf that already held works on like subjects by authors such as J. J. Thomson and Rutherford and Bohr. *The Mighty Atom* was said to be one of the best sellers of its day : in that respect, if in no other, it found congenial company when it was joined on the same shelf by a series of volumes from the fascinating pens of Eddington and Jeans. These, however, I need not tell you I have read and reread, to my entire pleasure and partial understanding.

II

If 'The Mighty Atom' was an arresting phrase, it was also an apt one. For we now know the atom to be indeed mighty in senses that were little suspected by the begetters of atomic theory. It has been mighty in sweeping away ideas that were found inadequate, in demanding fresh concepts, in presenting a new world for conjecture and experiment and inference, in fusing chemistry and physics into a single science. It is found to be mighty in the complexity of its structure and the variety of radiations it may give out when excited to activity. It has unravelled for us the bewildering tangle of spectroscopic lines. And, most surprising of all, the atom, how-

ever seemingly inert, is mighty in being a magazine of energy which, for the most part, it locks safely away. This is fortunate, for if the secret were discovered of letting loose the atomic store we should invite dissolution at the hands of any fool or knave. And it is also fortunate that in the furnace of the sun, at temperatures far higher than those of our hottest terrestrial infernos, the stored energy of the atom is drawn upon, as we believe, and has been drawn upon for ages, to keep up that blessed radiation which makes man's life possible and is the source of all his power.

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energy is given out when a weight falls from one to another landing of a staircase. We may speak of the landings as energy levels. The radiation which issues when an electron falls from one energy level to another constitutes what is called a photon.¹ It has two aspects, behaving in one like a particle and in the other like a group of waves, and at present we have to accept both, though we cannot fully reconcile them. The photon carries a definite quantity of energy and is characterized by a definite frequency of vibration. Its energy depends on the two levels between which the electron falls, and this determines the frequency of the vibration which the photon conveys, for the frequency is equal to the energy divided by that mysterious constant of nature, the Quantum of Action discovered by Planck. In any element all the atoms have the same set of energy levels : these contribute to the emission spectrum and account for its groups of spectral lines. In heavy atoms there are many energy levels, and consequently very many lines appear in their spectra.

I will not weary you with details that are now fairly familiar. What we have to realize is that all matter consists of the two kinds of electricity, protons and electrons, held apart we do not know how. To the early experimentalists who electrified rods of resin or glass by rubbing them, electricity seemed no more than a curious attribute of matter : now we regard it as matter's very essence—the ultimate stuff out of which every atom is built. If you ask, What is electricity ? there is no answer, save that it is a thing which exists in units of two sorts, positive and negative, with a strong attraction for each other, and that in any atom you find them somehow

¹ We owe the name 'photon' to Prof. G. N. Lewis of Berkeley, California, who proposed it in a letter published in *Nature* of December 18, 1926.

held apart against that attraction, with a consequent storing of potential energy. They are prevented from coalescing, although the difference of potential between them is nearly a thousand million volts. Why they do not flash together is a mystery—one of the many mysteries which physicists have still to solve.

Engineers are accustomed to the idea of storing energy in a condenser by charging the opposed plates to a potential of a few scores or hundreds or thousands of volts. That is done by transferring some of the crinoline electrons from one to the other plate: it involves only a minute supplementary separation, which disappears when the condenser is discharged. In every atom we have a permanent separation of electricities; the protons and electrons look at one another, so to speak, across an immensely greater dielectric gulf which no laboratory operation ever causes them to bridge. That is why every atom is a magazine of energy, the quantity of which (mc^2) is proportional to the atom's mass.

Any of the usual operations of the electrical engineer, such as charging and discharging a condenser or a storage battery, or driving a dynamo and conducting electricity from it to a distant station where it can actuate a motor or heat the filaments of lamps to incandescence, may be described as the setting up and the breaking down of a comparatively small extra difference of potential between the opposed electricities in some of the atoms of the engineering plant. In every process of industrial electricity, on whatever scale, what happens is a temporary enlargement of the potential difference which always exists between electrons and protons, and then a return to what may be called nature's *status quo*. But those supplementary differences of potential which the engineer first superimposes and then allows to disappear are exceedingly small, even at their greatest, in comparison

with the gigantic difference which the normal condition of the atoms itself involves.

A notable event of the year is the strong evidence which Dr. Chadwick of the Cavendish Laboratory has found for the existence of what is called the neutron—a type of particle in which an electron and a proton are associated in particularly close juxtaposition. There is a like close association between electrons and protons in the nucleus of any heavy element, but it had not previously been discovered in a single isolated pair. Twelve years ago Lord Rutherford conjectured the existence of such a particle and described the properties it should possess. Its excessive smallness and density, together with its lack of an external electric field, give it a unique power of penetrating matter. It is too slim to be confined under pressure in any vessel : it will simply slip through the walls. The normal hydrogen atom has the same two constituents, one proton and one electron, but in nothing like the same intimacy of association, for the hydrogen atom wears its electron as a bulky crinoline which confers on it an immensely greater volume. The neutron, on the other hand, may be said to have taken the crinoline off, folded it up and put it in its pocket. Not to be too fanciful, we may at least describe the partners as clasping one another so tightly that the electron has ceased to be a fender ; none the less, as a unit of negative electricity it still serves to give electrical balance to the pair. Though so close together the two constituents of the neutron remain separate and distinct, parted by nearly as many million volts as in a hydrogen atom. In this hitherto unknown particle, whose existence the experiments of Dr. Chadwick seem to have definitely proved, we have a new physical entity of extraordinary interest and a powerful tool for further research.

Lord Rutherford was the first to discover and name

the nucleus. It is the inner sanctuary of the atom, the repository of secrets many of which have yet to be disclosed, almost unapproachable, not only because of its smallness but because of the electric field in which it is encased. Recognizing the nucleus to be a richly charged strong-room, Rutherford has spared no effort to break it open. He has submitted it to a furious bombardment, using as missiles the alpha particles which radioactive substances project. These particles, each consisting of four protons and two electrons compactly built together, have the necessary velocity and energy to penetrate to the atom's heart. Rutherford had perforce to fire into the brown : he could not aim his gun, nor even tell when it would go off : the chances of a hit were no more than one in many millions. But hits were in fact obtained—hits so effective that they chipped off protons and caused the missile to be absorbed, thus realizing the dream of the alchemist by making one element change into another. That was a dozen or more years ago : since then his attack has lost none of its severity. It has been taken up under his guidance by a school of workers and many further secrets of the nucleus have been revealed.

Quite recently two of his disciples have gone one better, as disciples sometimes do, to the joy of their lords. Dr. Cockcroft and Dr. Walton have used missiles of their own making instead of those that come spontaneously and intermittently from substances such as radium or thorium. By beautiful devices they have applied their knowledge of electrical engineering and their mastery of electrical technique to project single protons into the nucleus of lithium, using a steady potential of several hundred thousand volts to give the projectile sufficient penetrating power. An atom of lithium has (usually) seven protons and four electrons in its nucleus ; the other three electrons constitute the crinoline. Here again

it was a case of firing into the brown: out of millions of shots a few reached their billet. When the projected proton forces an entry into the lithium nucleus it creates a domestic disturbance of the liveliest kind. For with the seven protons already in occupation it makes an eighth; the group then splits into two sets of four, each taking two of the electrons, and they fly violently apart with an energy drawn from the atomic magazine. The result is that two helium atoms are formed. This is a notable achievement, the first artificial splitting of the atom by a laboratory process in which there is no recourse to the violent projectiles which radioactive substances provide. It has been followed up by successfully applying the same method to break up the atoms of other elements.

It is a satisfaction to learn that in all the encounters and emissions and absorptions that are studied among atoms and photons and the parts of atoms there is, so far as we yet know, strict compliance with the accepted principles of conservation in respect of momentum and energy and mass, though matter (in the ordinary sense) is liable to transformation into energy and energy into matter. When radiation is emitted some matter disappears, for the atom that emits it loses a little of its mass; when radiation is absorbed a like quantity of matter comes into being.

But the engineer finds himself obliged to admit that no mechanical model of the atom can be expected to give an adequate picture of that strange new world. Our mechanical ideas are derived from the study of gross matter, which is made up of vast aggregates of atoms, and any model must share the limitations this implies. It is futile to explain the constitution of the atom in terms applicable to gross matter, just as it would be futile to study the psychology of an individual by observ-

ing only the movements of crowds. So we must expect to find within the atom and among its parts qualities and actions different in kind from those we know, and paradoxes which without a wider vision we cannot interpret. Such a paradox indeed confronts us at the present time, when we try to harmonize the wave aspect and the particle aspect of the photon, of the electron, and indeed of matter itself. These things are still a mystery—a riddle which some day we may learn to read. Meanwhile we do well to remember that any attempt to portray the structure of the atom in the language of ordinary experience is to give undue significance to symbols and analogies that are more or less invalid. Qualifying phrases like 'so to speak' or 'as it were' cannot be escaped. They are confessions that the image is inevitably a distortion of the reality it is intended to suggest.

III

Let us now glance back to the early days of the Association, and trace a little—a very little—of what it has done for the advancement of science, both pure and applied. The two inevitably march together. Between discovery and invention there is, in effect if not always in form, a close partnership with a constant interchange of advantage. No discovery, however abstract, is safe from being turned to practical account ; on the other hand, few if any applications fail to react in stimulating discovery and providing the experimentalist with more effective weapons of attack.

From the first the Association took cognizance of engineering as one of the subjects it was created to advance. One of its earliest acts, and a very wise one, was to invite reports on the state of science : these were called for in many different fields and were written by

the best available experts. In the first batch of such reports were two that dealt with engineering, one on the Strength of Materials and the other on Hydraulics. As it happened, they were of very unequal merit ; but they are alike in this, that they demonstrate how conspicuous was the lack of science on the part of early British engineers.

The engineers of those days were big professional figures. They had covered the country with a network of roads and bridges and canals ; they had drained the fens ; they had built harbours and lighthouses. By multiplying factories, by extending the uses of coal and iron, they were laying the foundations of that commercial supremacy which, so long as it lasted, we took for granted as a sort of national right. They had taught the world how to light towns by gas, and were beginning to drive ships by steam. Above all, they had shown that a new era of locomotion was about to set in. A railway connecting Liverpool with Manchester had been opened : its success was proved, and schemes were projected that would soon utilize labour on a large scale for a host of tunnels and cuttings and embankments, and so relieve the scourge of unemployment which—as we also know—follows the scourge of war. The engineering pioneers were sagacious men who put their faith in experience ; they knew little of theory and cared less. Instinct and personality carried them through difficulties of a kind that science might have helped them to solve or to avoid. They had the sense to profit by their own mistakes.

It is significant that in 1832, when the British Association called for a report on the present state of our knowledge of Hydraulics as a branch of engineering, the terms of reference included this curious phrase : ‘ Stating whether it appears from the writings of Dutch, Italian

and other authors that any general principles are established in this subject.'

The report was written by George Rennie, a son of the greater Rennie who left us a monument of his genius—I wish I could say an imperishable monument—in Waterloo Bridge. After giving a good summary of the work of foreign theorists the reporter remarks :

' It only remains for us to notice the scanty contribution of our own countrymen. While France and Germany were rapidly advancing upon the traces of Italy, England remained an inactive spectator of their progress.'

It is clear that there was much need for the scientific leaven which the new Association could, and did, provide.

Another of the early concerns of the Association was with the performance of steam engines. At the date of our foundation more than fifty years had passed since the inventions of Watt provided an engine fit to serve as a general means of producing power. Its earliest application, and still at that date its most common one, was in the pumping of mines. Engineers took a professional and even sporting interest in what they called its 'duty,' meaning the amount of water pumped through a given height for each bushel of coal consumed. Nevertheless it is a remarkable fact that neither they nor the physicists of that period had any notion that the process involved a conversion of heat into mechanical work. It is difficult for us now to imagine a world of physics and engineering where the idea had not yet dawned that there was such a thing as energy, capable of protean transformations, but in all of them conserving its total amount. Enlightenment was soon to come, and our meeting-rooms furnished the scene. In 1843 Joule brought before one of the sections his first determination of the mechanical equivalent of heat. He spoke with the modesty natural

—in those days—to a man of twenty-four. His paper was received in chilly silence. Two years later, after further experiments, he reappeared ; but again no notice was taken of the heresies of a youthful amateur. Nothing daunted, he prepared a fuller case for the Oxford meeting of 1847, perhaps remembering that Oxford is the home of lost causes. In a narrative written many years later, Joule has told how the Chairman suggested that as the business of the Section pressed he should not read the paper, but merely give a brief account of his experiments :

‘ This [he says] I endeavoured to do, and discussion not being invited, the communication would have passed without comment if a young man had not risen in the Section and by his intelligent observations created a lively interest in the new theory. The young man was William Thomson.’

But Thomson, though deeply interested, was not at first convinced. Nearly four years more were to pass before he satisfied himself that the doctrines of Joule did not clash with the teachings of Carnot, of which he was then an enthusiastic proselyte. At length he became a convert ; he saw, as we should now say, that the First Law of Thermodynamics was in fact consistent with the Second. Then indeed he accepted the principles of Joule in their entirety and was eager in their support. Quickly he proceeded to apply them to every part of the physical domain. Along with Clausius and Rankine he formulated the principles which govern the whole art of producing power by the agency of heat. The steam turbine of Parsons, the gas engines of Otto and Dugald Clerk, the oil engines of Daimler and Diesel, with all their social consequences in making swift travel easy by road and possible by air, are among the practical results. On the same thermodynamic foundation was built the

converse art of mechanically producing cold, which we employ in ever-increasing measure for the import and storage of our food. Joint experiments undertaken by Joule and Thomson led to a further discovery which later enabled the process of refrigeration to be carried very near to the limit of coldness which Thomson himself established as the absolute zero. In the hands of Linde and Claude the 'Joule-Thomson effect' as a means of producing extreme cold has created new industries through the liquefaction of air and the separation of its constituents by methods of fractional distillation. However cold, however near the absolute zero, was the Association's first reception of Joule, we may claim that in effecting a conjunction between him and Thomson it made amends. Their meeting in 1847 ushered in a new era both of scientific theory and of engineering practice.

Of the Association's many other services there is little time to speak. When the telegraph developed in the middle of last century and spread itself across the Atlantic, largely under the guidance of that same William Thomson (whom later we knew as Lord Kelvin), there were no accepted units in which electrical quantities could be measured and specified. The scientific world was as badly off then for a standard of electricity as the commercial world is now for a standard of value. The need of electrical standards was urgently felt, by none more than Thomson himself. He stirred the Association to act: a strong committee was set up, and in time its work served as a basis of international agreement. There is no danger that any country will wish to 'go off' the standards thus established. To settle them was an incalculable boon to science no less than to technics. It paved the way for the revolution of the eighteen-eighties, when electricity passed, almost suddenly, from being no more than the servant of the telegraph to be master of a great

domain. It was then that the electric light and the electric transmission of power gave it a vastly extended application, and the fundamental discoveries of Faraday, the centenary of which we lately celebrated, came into the kingdom for which they had waited nearly fifty years.

Another notable achievement of the Association was to promote the establishment of a National Physical Laboratory. Informal talks at our meetings in the nineties led to the appointment of a committee which moved the Government of the day to take action. The Laboratory was constituted, and Sir Richard Glazebrook was appointed its first head. What it has become in his hands and the hands of his successor, Sir Joseph Petavel, does not need to be told. From small beginnings it has grown to be an influential factor in the world's scientific progress, and a legitimate subject of national pride.

Another by-product of quite a different sort is the memorial to Charles Darwin which we hold as trustee of the nation and of all nations. At our meeting in 1927 the President, Sir Arthur Keith, spoke in his address of the house where Darwin lived and worked, pointing out how admirably it would serve as a monument of the great naturalist. No sooner was the suggestion published than a donor came forward whose devotion to the memory of Darwin expressed itself in a noble gift. Sir Buckston Browne not only bought and endowed Down House, but arranged with pious care that the house and its grounds should exhibit, so far as was possible, the exact environment of Darwin's life. The pilgrims who now visit this shrine in their thousands see Darwin's study as it was when the master thought and wrote, and can reconstruct the habit of his days. There could not be a more appropriate memorial. Its custody by the Association involves obligations which are by no means small, and we may claim that they are worthily fulfilled.

One may safely say that there is no department of scientific endeavour our meetings have not aided, no important step in the procession of discovery they have not chronicled. It was at our meeting of 1856 that Bessemer first announced his process of making a new material—what we now call mild steel—by blowing air through melted pig iron. Produced in that way, or by the later method of the regenerative furnace and the open hearth, it soon revolutionized the construction of railways, bridges, boilers, ships, and machinery of all sorts, and it now supplies the architect with skeletons which he clothes with brick and stone and concrete. It was at the Oxford meeting of 1894 that Lodge demonstrated a primitive form of wireless telegraph based on the experiments of Hertz, a precursor of the devices that were brought into use a little later through the practical skill and indefatigable enterprise of Marconi. At the same meeting there was an epoch-making announcement by the late Lord Rayleigh. His patient weighings of the residual gas which was found after depriving air of all its oxygen led him to the discovery of argon. That was a surprise of the first magnitude; it was the herald, one may say, of the new physics. Next year his colleague Ramsay presented other members of the family of inert gases. It is curious to recall the indifference and scepticism with which these really great discoveries were received. Some of the chemists of that day seem to have had no use for inert gases. But the stones which the builders were at first disposed to refuse are become headstones of the corner. In the architecture of the elements they fill places that are distinctive and all-important; they mark the systematic sequences of the periodic law. In a metaphor appropriate to atomic physics we may describe them as coy ladies with a particular symmetry in their crinoline of electrons, unresponsive to advances

which other atoms are ready to make or to receive. Inert though they be, they have found industrial uses. Helium fills airships ; argon fills incandescent lamps ; and neon, so modest a constituent of the atmosphere that you might think it born to blush unseen, has lately taken to blushing deliberately and even ostentatiously in the shop-signs of every city street. In the field of pure science it was neon, outside the radioactive elements, that first introduced us to isotopes. And helium has a greater glory as the key to radioactive transformations and historian of the rocks. Disciples of evolution should be grateful to helium for delivering them from the cramping limits of geological time which an earlier physics had mistakenly imposed.

My own recollection covers many surprises that are become commonplaces to-day : the dynamo, the electric motor, the transformer, the rectifier, the storage battery, the incandescent lamp, the phonograph, the telephone, the internal-combustion engine, aircraft, the steam turbine, the special steels and alloys which metallurgists invent for every particular need, wireless telegraphy, the thermionic valve as receiver, as amplifier, as generator of electric waves. To that last we owe the miracle of broadcasting. Who, a generation ago, would have imagined that a few yards of stretched wire outside the window and a magic box upon the sill should conjure from adjacent space the strains of Beethoven or Bach, the exhortations of many platforms, the pessimism natural to those who forecast the weather, and the optimism of orators who have newly dined ?

Sounds and sweet airs, that give delight and hurt not.
Sometimes a thousand twanging instruments . . .
And sometimes voices . . . that, when I waked,
I cried to dream again.

I don't know any product of engineering more efficient than that magic box. It needs no attention ; it is always

ready for service ; and when you tire of it you have only to switch it off. A blessing on it for that ! Heard melodies may be sweet, but those unheard are often sweeter. Do you ever reflect, when you pick and choose among the multitude of airs and voices, or shut out all from your solitude of thought, that they are still there, physically present, individual, distinct, crowding yet not interfering, besetting you though you do not perceive them, silent until you determine that one or another shall catch your ear ? Go where you will, to the ocean or the wilderness or the Pole, you cannot escape that vast company of attendants ; they come to you, unheard, unseen, from every quarter of the globe with a swiftness no other messengers approach. Is any fairy tale so strange as that reality ? In all the wizardry of science surely there is nothing more wonderful than this.

IV

Among the inventions which have revolutionized the habits of modern man some were developed by steps that were mainly empirical. Others, especially those that are most recent, have had a very different history : science has been their incubator and their forcing-house. In the advance of any invention there is bound to be an element of trial and error, but when the scientific method is consistently applied the proportion of error is small and progress is swift. We see this exemplified in the development of mechanical flight, where one difficulty after another has been vanquished by aid of well-directed theory and well-related experiment. Or consider that immensely important modern art, the art of communication by telegraph and telephone, by wire and ' wireless '. There the efforts of scientific engineers were dominant at every stage, and it was through their guidance that

the art quickly achieved its world-wide triumphs. It is true that in the story of long-distance radio-telegraphy there was a striking episode where the courage of the practical inventor forestalled the discovery of a recondite scientific fact. It happens that the wireless waves from a radio-station, instead of shooting out straight into space as such rays might be expected to do, become bent in the upper regions of the atmosphere, taking a surprising and convenient curvature which enables them to travel round the surface of the globe. An unlooked-for kindness on the part of Nature has provided what we now call the Heaviside layer by which she works this happy trick. The strange fact that the rays could somehow bend was recognized and applied by Marconi before anybody had a rational explanation to suggest. Speaking broadly, however, it was scientific nursing of the infant art, and scientific culture throughout its period of growth, that brought it to the splendid manhood which now blesses mankind.

I think we may regard the whole art of electrical communication as an unqualified blessing, which even the folly of nations cannot pervert: in that it differs conspicuously from some other inventions. Before it came into use the sections of civilized man were far more separate than they will ever be again. There could be scant sympathy or understanding, little chance of effective co-operation among communities scattered over the earth. A calamity might fall on one and be already old before others knew of it to offer help. Now we have all the world made practically instant in its interchange of thought. Through this physical linkage, which annihilates both space and time, there is opened a possibility of quick discussion, common resolution, simultaneous action. Can you imagine any practical gift of science more indispensable as a step towards establishing the

sense of international brotherhood which we now consciously lack and wistfully desire? Should that aspiration ever become more than a dream we shall indeed have cause to bless the creators of electrical communication, to praise them and magnify them for ever.

In the present-day thinkers' attitude towards what is called mechanical progress we are conscious of a changed spirit. Admiration is tempered by criticism; complacency has given way to doubt; doubt is passing into alarm. There is a sense of perplexity and frustration, as in one who has gone a long way and finds he has taken the wrong turning. To go back is impossible: how shall he proceed? Where will he find himself if he follows this path or that? An old exponent of applied mechanics may be forgiven if he expresses something of the disillusion with which, now standing aside, he watches the sweeping pageant of discovery and invention in which he used to take unbounded delight. It is impossible not to ask, Whither does this tremendous procession tend? What, after all, is its goal? What its probable influence upon the future of the human race?

The pageant itself is a modern affair. A century ago it had barely taken form and had acquired none of the momentum which rather awes us to-day. The Industrial Revolution, as everybody knows, was of British origin; for a time our island remained the factory of the world. But soon, as was inevitable, the change of habit spread, and now every country, even China, is become more or less mechanized. The cornucopia of the engineer has been shaken over all the earth, scattering everywhere an endowment of previously unpossessed and unimagined capacities and powers. Beyond question many of these gifts are benefits to man, making life fuller, wider, healthier, richer in comforts and interests and in such happiness as material things can promote. But we are

acutely aware that the engineer's gifts have been and may be grievously abused. In some there is potential tragedy as well as present burden. Man was ethically unprepared for so great a bounty. In the slow evolution of morals he is still unfit for the tremendous responsibility it entails. The command of Nature has been put into his hands before he knows how to command himself.

I need not dwell on consequent dangers which now press themselves insistently on our attention. We are learning that in the affairs of nations, as of individuals, there must, for the sake of amity, be some sacrifice of freedom. Accepted predilections as to national sovereignty have to be abandoned if the world is to keep the peace and allow civilization to survive. Geologists tell us that in the story of evolution they can trace the records of extinct species which perished through the very amplitude and efficiency of their personal apparatus for attack and defence. This carries a lesson for consideration at Geneva. But there is another aspect of the mechanization of life which is perhaps less familiar, on which I venture in conclusion a very few words.

More and more does mechanical production take the place of human effort, not only in manufactures but in all our tasks, even the primitive task of tilling the ground. So man finds this, that while he is enriched with a multitude of possessions and possibilities beyond his dreams, he is in great measure deprived of one inestimable blessing, the necessity of toil. We invent the machinery of mass-production, and for the sake of cheapening the unit we develop output on a gigantic scale. Almost automatically the machine delivers a stream of articles in the creation of which the workman has had little part. He has lost the joy of craftsmanship, the old satisfaction in something accomplished through the conscientious exercise of care and skill. In many cases unemployment

is thrust upon him, an unemployment that is more sadening than any drudgery. And the world finds itself glutted with competitive commodities, produced in a quantity too great to be absorbed, though every nation strives to secure at least a home market by erecting tariff walls.

Let me quote in this connection two passages from a single issue of *The Times*.¹ In different ways they illustrate the tyranny of the machine. One is this :

'The new Ford works built upon a corner of Essex ... will soon be able to produce motor-cars at the rate of two a minute.'

The other comes from Moscow. It also relates to the mass-production of motor-cars, and indicates how Russia is reaching out towards a similar perfection under the austere stimulus of the Five Years' Plan :

'The Commissar lays down dates for the delivery of specified quantities by each factory and invests twenty-one special directors with extraordinary powers to increase production, threatening each director with personal punishment if deliveries are belated.'

We must admit that there is a sinister side even to the peaceful activities of those who in good faith and with the best intentions make it their business to adapt the resources of Nature to the use and convenience of man.

Where shall we look for a remedy ? I cannot tell. Some may envisage a distant Utopia in which there will be perfect adjustment of labour and the fruits of labour, a fair spreading of employment and of wages and of all the commodities that machines produce. Even so the question will remain, How is man to spend the leisure he has won by handing over nearly all his burden to an

¹ *The Times*, June 25, 1932.

untiring mechanical slave? Dare he hope for such spiritual betterment as will qualify him to use it well? God grant he may strive for that and attain it. It is only by seeking he will find. I cannot think that man is destined to atrophy and cease through cultivating what after all is one of his most God-like faculties, the creative ingenuity of the engineer.

1932

II

A CENTURY OF INVENTIONS

BEING THE 'JAMES FORREST' LECTURE, 1928, DELIVERED
ON THE OCCASION OF THE CENTENARY OF THE INSTITU-
TION OF CIVIL ENGINEERS

LONG ago, as the nineteenth century was drawing to its close, I delivered a 'James Forrest' lecture.¹ The honour of being invited to serve again entails a responsibility which is all the heavier because this time the lecture is an item in the celebration of our centenary. When I lectured before, I was free to select a department of science in which I was then a worker, by way of illustrating, in accordance with the founder's wish, the interdependence of abstract science and engineering; now, though the general purpose is the same, I am asked to survey an immensely wider field. In those days I was young, and took a part, albeit a small one; now I am old and mainly a spectator, who at the best may draw his arm-chair up to the footlights and discourse to the audience about the play. The play itself goes on and on, endlessly, with never a curtain: its interest does not flag; and the stage grows so big and so crowded with actors and incidents as to bewilder the most observant critic. He must perforce confine his attention to but a few aspects and episodes of a drama which daily becomes more and more intricate, vast, and elusive.

¹ 'Magnetism.' See page 116 of the present volume.

The Council, when inviting this address, suggested a very comprehensive text, namely, a prediction which Thomas Tredgold added to the definition of Civil Engineering which he drew up for the petition for a Royal Charter presented in 1828. It ran thus :

'The scope and utility of Civil Engineering will be increased with every discovery in philosophy, and its resources with every invention in mechanical or chemical science.'

Seldom, surely, has a prophecy been so justified in the event. The history of engineering during the century which has passed since these words were written is in its main features the story of their fulfilment. Every advance in scientific theory has increased the engineer's mastery of the material world. Discoveries which at first may have seemed wholly unserviceable to him have in fact furnished new points of departure, leading in ways that were often unforeseen to enlargements of his many-sided art.

It may be doubted whether even Tredgold, with all his vision, saw the other side of the picture ; whether he realized the beneficent reaction by which science was itself to profit. But we, at any rate, see it now. We see how developments in science are fostered and even initiated by industrial requirements, by engineering enterprise ; how inventions that were made for the purpose of serving a public need have widened the outlook of science and given it new tools for research. Nowadays theory and practice march together in such close association that it is often difficult to distinguish them as separate figures in the procession. In chemistry, in metallurgy, in thermodynamics, in electricity, who would venture to apportion the credit for progress, as between the man who pursues abstract truth and him who strives after technical application ? And looking back we may assert

that there has from the first been some mutual obligation, not indeed so constantly operative as it is to-day nor so clearly admitted, but often very influential. From modest beginnings physical science and engineering have advanced, side by side, and in the advance their intimacy has developed ; they have discovered the benefit of relationship and the relationship has itself become closer. A century ago they were both sturdy infants, playing, one may say, in more or less separate nurseries, sometimes meeting and perhaps sometimes quarrelling a little. Now, adult and masterful, they are partners in one firm, still conscious—as partners may be—of differences in temperament and taste and viewpoint, but very conscious also of the strength that comes from co-operation.

To-day we can take no more than an aviator's survey—what used to be called a bird's-eye view. Your Council has chosen for the purpose an old bird, who, if he is not so strong on the wing as he was, has the doubtful advantage of having seen more than half a century pass since he began to teach engineering. I recall as a boy finding inspiration in an account of the doctrine of the conservation of energy then published as a new gospel—a doctrine which flooded with light much that had been very dark in earlier attempts to co-ordinate mechanical ideas. My recollections go back to a period before the coming of the oil engine, of the dynamo, of the electric motor and the transformer, when the only practical application of the electric current was in telegraphy, when the arc lamp was a scientific curiosity and the telephone had still to be born. It is something to have witnessed the whole pageant of electrical engineering display itself before one's own eyes, from tiny beginnings to its present greatness ; to have seen the dream realized of a distribution of power from central stations ; to have watched each stage in the development of the steam turbine and its use on

land and sea ; to have observed the internal-combustion engine arrive as a modest ally to steam, and gradually turn into a serious rival, after effecting a social revolution by making transport by road easy and transport by air possible. These things are familiar to you all ; but it is perhaps to the old, who saw their first coming, who knew a simpler, homelier world before they came, that they make their strongest appeal. To me, who began engineering experience with the telegraphy of the early seventies, it is much to have been a spectator of the wizardry which has so transformed the art of communication that the spoken word literally goes forth to the end of the world.

But in this review we have to go back further than the reach of even the longest individual memory. Try to realize what engineering meant in 1828, what was its relation to the science of the day, and what in fact was, in that day, the state of science.

The engineers of that period were mainly concerned with roads, bridges, and canals ; the era of railways was about to begin. Macadam had just been appointed Surveyor General of roads. He and our first President, Telford, had contributed to convert the roads from sloughs of despond into highways in which the wayfaring man could not err, fit, as the President observed in his inaugural address, for their Scottish compatriots to use in the continued invasion of England. A few years earlier Telford had spanned the Menai Straits with a chain bridge, to take the Holyhead road ; and the Southwark bridge, with its cast-iron arches, was erected to the designs of Rennie. But these structures were exceptional ; it was a rare thing then to build a bridge of iron. Shortly before that Rennie had done a far finer work, in the beautiful Waterloo bridge, whose fate is now a matter of anxious concern. It was in stone that

the pioneers erected their graceful and enduring monuments of early engineering skill : in bridges, lighthouses, docks, and harbours. They made their mark, too, in the cutting of canals. They had covered England with a network of waterways whose economic importance we, children of another age, find it difficult to estimate aright. During the half-century or so which precedes the date we celebrate, canal projects were promoted with something of the enthusiasm which later attended the development of railways : the commercial success of some ventures was so conspicuous as to bring about a 'canal mania'. Speculative fever is the last thing we think of now in looking at these tranquil relics of an almost vanished usefulness, but in the years before railways opened a prescient investor in canal stock might have had the same good fortune as modern venturers sometimes find in such things as artificial silk or Marconis.

The success of the canals wrought their ruin. They developed a public need which became too great for them to satisfy, and drove men to seek a solution in the creation of railways. The canal interest, strong though it was, could not stay the coming of a more adaptable and quicker method of traction. In engineering, as in other affairs, the better is the enemy of the good. Naturally the good did not love its enemy. Perhaps it was an owner of canal shares who bewailed his sufferings as a householder near the line of an early railway by writing in this fashion to a newspaper : ' Judge of the mortification whilst I am sitting comfortably at breakfast with my family, enjoying the purity of the summer air, in a moment my dwelling, once consecrated to peace and retirement, is filled with dense smoke or foetid gas ; my homely, though cleanly, table covered with dirt, and the features of my wife and family almost obscured by a polluted atmosphere. Nothing is heard but the clanking

iron, the blasphemous song, or the appalling curses of the directors of these infernal machines.'¹

Though the Stockton and Darlington line, first of such public enterprises, was opened in 1825, it was not till 1829 that Stephenson's 'Rocket,' when tried against competitive engines on a section of the Liverpool and Manchester Railway, settled the much-disputed question whether steam locomotives should be used, and determined also the general lines of subsequent locomotive design.

The steam engine, beginning as a device for pumping water out of mines, had been adapted by Watt and his followers to the driving of machinery in factories, and had thereby become a potent agent in the industrial revolution which followed the Napoleonic wars. It had been applied experimentally to drive carriages on roads, and had established its position, especially in America, as the motive power of paddle boats for river traffic. To a small extent steam was being adopted as an auxiliary in sailing ships, and reformers were urging that the Navy should give it a trial—alleging what seems to us the curious reason that a steam ship would cost less to build than a sailing ship. We have not found the *Hood* cheaper than the *Victory*.

Watt's prejudice against the use of high-pressure steam for a long time dominated English practice. Nevertheless, Jacob Perkins, rightly described by a contemporary as 'an experimenter of no common cast', ventured even before 1828 on pressures such as would still be considered very high. He exhibited a piece of steam artillery which, under a pressure of sixty-five atmospheres, projected nearly one thousand musket balls per minute. But Perkins was one of those unfortunate inventors who are born before their time. What

¹ Quoted by Jackman, *Transportation in Modern England*, p. 497.

is relevant for us to notice is, that in those days the theory of steam was even more rudimentary than the practice ; the early development of the steam engine proceeded without the guidance which it would have had if the properties of steam had been known. Carnot had already written his wonderful essay on the motive power of heat. But it had fallen flat. Its meaning was not appreciated ; and at the time of which I speak, the very alphabet of thermodynamics had still to be framed.

Remember that these early steam engineers had no idea that what they were doing was to convert heat into mechanical work. Many years were to pass before the notion of energy, as a thing neither produced nor destroyed, was to become an established part of natural philosophy ; before Joule determined the mechanical equivalent of heat, and the first principles of the subject were formulated by Kelvin and Rankine and Clausius. But it may fairly be claimed that the way was prepared for these conceptions by the work of the engineers, by the invention and frequent use of the indicator, by Watt's numerical definition of the term 'horse-power', and by the sporting interest of the Cornish mine managers in the 'duty' of their engines, a figure which expressed the relation of what we now call the work done to the coal consumed.

I say 'what we now call the work done', for it is curious to notice that a hundred years ago the word 'work' had not acquired the mechanical meaning we now give it. Even so late as 1841 Whewell, afterwards Master of Trinity, an eminent writer on mechanics, with a reputation for omniscience which was more possible then than now, published a treatise on the Mechanics of Engineering 'intended for use in Universities and in Colleges for Engineers', in which a chapter is devoted to what he calls 'Labouring Force'. This, in fact, is

nothing else than *work*. It is, he says, 'measured by the product of the resistance overcome and the space through which it is overcome', and he adds that Poncelet and other French engineers 'call it *travail*'. But the obvious English equivalent had still to make its way into our scientific phraseology.

When one looks at the technical literature of that period one is sorry for the early student of engineering. Physicists and engineers alike were groping their way, confusedly, towards mechanical ideas which were as strange then as they are familiar now. The mathematical theory of elasticity is described by its historian Todhunter as having had its birth in 1821, when Navier first gave the equations for the equilibrium of elastic solids. Navier had brilliant colleagues among the other mathematicians of France. But between them and the stolid practitioners of Westminster there was a wider difference than one of language or political sentiment. Their ways were not as our ways. Tredgold, in a preface to his *Essay on the Strength of Cast Iron*, which discusses the stresses in beams, goes so far as to repudiate the use of fluxions as unsound. He appears to have regarded a differential coefficient as a device for 'forcing the assent rather than convincing the judgment'. This prejudice against the calculus remained for long a serious handicap to the British student of engineering. Teachers misspent their ingenuity in dodging the calculus ; they often led the student to think of it as mysterious and unattainable when he ought to have been learning not how to avoid, but how to use what is really an indispensable intellectual tool. That bogey is now pretty well laid, thanks in great part to the unconventional yet effective teaching of the late Professor John Perry.

Not less than mechanics and heat, the science of electricity was still in its infancy. Chimerical ideas found

vent in engineering papers about the possibility of driving ships by the consumption of a little zinc in a galvanic battery. One sanguine inventor estimated the cost of propelling a ship in this way at 3s. 4d. a day.¹ Ohm's Law had been formulated in 1825, but in the absence of units and instruments of measurement its significance could not be understood. It was not till the requirements of the telegraph had to be met that engineers and physicists together attacked the problem of framing a logical system of electrical units, determined their magnitude, set up standards, and established practical means of comparing electrical quantities with them. The work was begun in the early sixties, mainly at the instigation of William Thomson, afterwards Lord Kelvin. It was done under the auspices of a Committee of the British Association, of which the secretaries were Clerk Maxwell the physicist, and Fleeming Jenkin the engineer. What it accomplished was an incalculable boon to the investigator in pure science no less than to the technician.

To be able to *measure*—that, as Lord Kelvin used to say, is in any subject the first step towards real scientific knowledge. Till you can measure quantities and express them in numbers you may have the beginnings of knowledge, but you cannot claim to have reached even the beginnings of science. Not in electricity only, but in mechanics, in heat, in all the properties and actions of matter where engineers and physicists find common ground, it is through the alliance between science and practice that the art of measurement has been evolved. In the beginning came geometry, and the word itself tells a tale, reminding us that the origin of mathematics was the practical need to measure land. And all through the century now under review we see the same alliance

¹ See Stuart's *Historical and Descriptive Anecdotes of Steam-Engines*, 1829, vol. ii, p. 611.

at work, with the same give and take of advantage. It was to meet the needs of engineers that Whitworth brought precision into mechanism by laboriously creating for the first time a true straight-edge, a true plane surface, a satisfactory screw. But this was no less a service to science ; it made practicable the devices for measuring, the standards, the gauges, that are now familiar alike in the laboratory and the workshop. Our knowledge of physical constants and of the properties of materials, our units and scales and instruments and testers of all sorts, are for the most part offspring of the marriage of science with practice. They make science exact, and they allow engineering to be standardized.

It was to meet the rapidly growing needs of steam engineering that Regnault undertook his researches into the properties of steam, which led to the publication, in 1847, of tables and data that for long remained a classic of the engineer. Now, thanks to Callendar, Mollier, and other workers, we enjoy a fuller and more accurate knowledge of these properties than Regnault could achieve, hampered as he was by the uncertainties of early thermometry. The science of thermometry became definite only after Kelvin introduced the absolute scale of temperature—a brilliant philosophical conception which runs through all physical and chemical science like a thread of gold in a woven fabric. It guides the engineer to the ultimate standard of thermodynamic efficiency ; and it was from meditating on the action of heat engines that the inspiration came.

It was to meet the requirements of the naval architect that William Froude attacked the problem of ship resistance, devised the method of the experimental tank, and showed how measurements on the drag of small models might, through application of what is now called the principle of dynamical similarity, furnish data from

which to determine the power required at any speed to drive the largest ships. In more recent days the same principles, applied by aid of experimental wind channels to study the forces which air currents exert on model objects, have been a powerful factor in the development of aeronautics—an art whose beginnings many of us have witnessed and whose progress, sensational rapid, compels attention from day to day.

A new art, such as flying, becomes inevitably and at once a branch of applied science; it advances like a fire-engine in a crowded thoroughfare; it escapes the long period of empiricism through which the older arts had to pass while they were laboriously making their way into ordinary use.

It is to aid engineering no less than pure science that we now supplement private enterprise by the official organization of research. In this it must be admitted that we followed somewhat slowly the example set by continental neighbours. The National Physical Laboratory was promoted by the joint efforts of physicists and engineers. It was, from the first, fortunate in having for its head a man in the fullest sympathy with both schools of thought, who, for many years and with the happiest results, applied his faculty for leadership to build up an establishment whose work is accepted as authoritative and whose influence on the scientific development of engineering has been, and continues to be, profound. Sir Richard Glazebrook has himself dealt with 'The Interdependence of Abstract Science and Engineering' in a James Forrest Lecture delivered five years ago. No man could speak with a closer personal understanding and experience of the subject. In his hands the value of the Laboratory was so fully demonstrated that after a time, from being semi-official, it was made official—becoming a truly national laboratory,

administered by a new Government office, the Department of Scientific and Industrial Research.

That Department, established in 1916, remains with us as a beneficent legacy of the war. It is a notable item on the credit side of an account that is mainly one of debit. The war turned men's thoughts, as never before, to mechanical problems. From being questions of mere luxury or convenience, such problems became, almost suddenly, questions of national life or death. Physicists and mathematicians whose interests had been wholly abstract were brought, as it were, from the clouds to earth. They faced facts—often, one should add, to excellent purpose. With the community generally, applied science took on a new significance ; till then it had meant little to them ; they now saw it as a man struggling in the water sees a plank within his reach. Research, and the adaptations of research, from being treated with general indifference, were hailed as a way to public salvation—salvation not only from the immediate menace of the struggle itself, but (after that was past) salvation from the abiding danger of international competition and the burden to industry through waste and debt. The national intelligence was stirred ; blind eyes were opened. They have remained open, and the Department does much to keep them open. You have only to glance at its annual reports to see the great range of its activities. It undertakes researches of a type no private worker could attempt. It acts largely through committees, on which experts in one or another industry co-operate with men of scientific habit. I have served on such committees, and can bear witness to the benefit that comes of this co-operation. On one of them we are now approaching the end of a long and fruitful inquiry into the stresses which are caused in railway bridges by the passage of trains. It is a question of much practical

importance and of great complexity ; a complexity greater than any of us understood when the investigation began. I may safely say that the results we have reached would not have been attainable save by the association of representatives of railway engineering, experienced on the practical side, with others who were qualified to interpret the experimental data by the methods of an intricate mathematical analysis.

The Department also subsidizes young research workers. For a young worker, to attempt research is often educational, and he may discover a real aptitude. But we must not forget that researchers, of the best sort, are like poets ; they are born, not made. You may produce in this field competent hewers of wood and drawers of water, men who will usefully assist or follow a real leader. But the wind bloweth where it listeth ; no man who says, ' Go to, I will research,' can count on inspiration, and not even the draught in an air-channel will make dry bones live.

On the other hand, when the right man is found, there is no limit to his potential achievement. He may give the world a new idea ; he may create a new industry ; he may make for himself a name ; he may make, generally for others, a fortune. Of late the practice has sprung up in the great manufacturing corporations of engaging the services of a team of researchers, and placing the best laboratory equipment at their disposal. One is glad to know that this procedure has been found to pay. Some corporations take a wise line in giving the researchers a free hand—a roving general commission of inquiry—not limited to points of immediate utility. There are notable instances where this has led to discoveries and inventions which more than justify such a policy on its economic side.

Thirty years ago and more I used to be a professor of

engineering. In those days one was a missionary, a propagandist of the value of theoretical training. One had to preach, insistently, to the followers of an older rule-of-thumb that time spent in scientific study was not time wasted. All that is changed now. The younger generation of engineering professors cannot imagine how tactfully, how guardedly, we of a less enlightened age had to beg for tolerance, to plead as it were for our own existence. To me it marked the beginning of a new era when the head of a great engineering firm said, 'I want you to send me, regularly, some of your young men'. Now they all say that to the happier professors of to-day. From the big establishments representatives come beforehand to learn the names and qualifications of youngsters who are about to take their degree. The most promising are snapped up; all seem to find ready employment; they are paid for their work instead of paying a premium for the privilege of entry—though in truth they have much to learn of a kind no college can teach. This, surely, is evidence that engineers recognize the benefit of associating practice with science. Moreover, the constant flow of youths, so educated, into professional life makes always for a closer linkage, a quicker reaction, between the scientific outlook and the world of construction and design.

From time to time in the history of engineering we find a new idea born, resembling what biologists call a sport, which gives an unexpected turn to the process of inventive evolution. No one can confidently extrapolate the curve of engineering progress; its equation is liable to capricious change. And besides those occasional fresh departures we find, especially in modern times, that the scientific method is continuously at work, acting always as an auxiliary to experience in improving what is already familiar. Thus the influence of science is felt in two

ways : in occasional spectacular events which open up channels where the stream did not flow before, and also in constant guidance of established currents, giving them greater volume and a more favourable course.

Take an illustration or two from the history of metallurgy. In 1828 the only forms of iron available for construction on a large scale were pig iron, the product of the blast furnace, and puddled iron, the same product decarbonized in the reverberatory furnace. When railways began there was doubt whether rails should be cast or wrought. Wrought iron had Stephenson's support and won the day. But it was not easy for the output of puddled metal to keep pace with the rapidly increasing demand which arose for rails, for boiler plates, and presently also for ship plates when iron came into use as the material for building hulls. It became urgent to find some other way of obtaining iron in the malleable state. In 1856 Bessemer attacked the problem as an outsider who broke away from the traditions of the trade. His method was a sport, but no accident ; it was an outcome of scientific thought. His first success was quickly followed by failures which only stimulated him to investigate their cause and cure. The difficulties were overcome, and mild steel began slowly to take its place as the most valuable of all constructive materials known to the engineer.

A few years later the alternative process of the open hearth was developed by Siemens, not less novel, and not less an offspring of scientifically trained intelligence. Regenerative heating—an idea which had already found engineering expression in the Stirling air engine—secured the high temperature necessary for the molten bath. Less simple and less rapid than the process of Bessemer, it had the advantage of easier control ; it could be made static. Each method has its own field of usefulness ;

together they supply the world with nearly a hundred million tons of steel a year.

In more recent times electricity, which is the handmaid of every branch of engineering, has given the steel-maker additional types of furnace with large application in the blending and refining of special steels. Steel has become a word of many meanings. We have learnt, and are still learning, the amazing variety of characteristics which can be produced in a metal by adding regulated quantities of other substances. The study of alloys, both ferrous and non-ferrous, is an immense field of research in which the resources of chemistry and physics are placed at the service of the engineer. By their aid he learns how to obtain a product that will fit a special purpose. It is, in each case, a question not simply of composition but of heat-treatment, for the atoms are like a community of alien races, subject to collective excitement and liable in their stormy moments to assume new groupings which largely and permanently affect the properties of the piece.

By means of such study the engineer is now provided with cutting steels which have revolutionized workshop practice ; stainless steels whose use goes far beyond the requirements of the cutler ; mechanically strong and wear-resisting steels in a profuse variety ; magnetically hard steels which are retentive of magnetism to a degree not approached before. It would seem you have only to specify a new requirement, and the metallurgist finds an alloy that will meet it. You want a metal which will not change its dimensions with temperature, and he discovers Invar. You want a steel which will refuse to take up any magnetism, and he discovers manganese steel. You want a metal immensely susceptible to weak magnetic fields, with which to 'load' a telegraph cable, and he discovers Permalloy. You want a metal which

will combine the lightness of aluminium with something of the strength and ductility of mild steel, and he discovers Duralumin and the Y alloy.

It is a scientific process of high-temperature electrolysis that has made aluminium a commercial product. The designers of aircraft and of motor-cars appreciate its value, in the alloyed state, and one may conjecture that in many fields of engineering construction we are on the threshold of an aluminium age. A material, not too costly, which has nearly the strength of mild steel, with little more than one-third its weight, ought to have an unlimited future. It has even been suggested that for the new age we should look to the alloys of another and still lighter metal, magnesium. Research in these directions proceeds apace.

A century ago the development of the steam engine had not emerged from the empirical stage. A change came soon after 1850, when men began to think of energy as protean and imperishable. The mechanical theory of heat was established, and in 1859 Rankine published his *Manual of the Steam Engine*. Kelvin rediscovered Carnot, and the Carnot cycle came to be recognized as an ideal criterion of performance which no engine could conceivably surpass. Engineers strove to bring their engines nearer to that standard by compound expansion, by superheating, and by other means of reducing avoidable waste. They also strove to widen the interval between the temperatures at which the working substance took in and rejected heat, for the 'heat-drop' between these limits determines how much of the supply of heat is ideally capable of conversion into work. Boiler pressures went up and up: they are rising still. A committee of this Institution helped to spread a sound gospel by recommending the Rankine cycle as a basis of comparison with the results of tests, a cycle which differs from that of

Carnot only by assuming that no reversible process is followed in the return of the condensed water to the boiler. But it is interesting to notice that modern steam plants of the most efficient type have introduced a reversible process through the device of 'bleeding', which enables the condensate to be heated step by step on its way back to the boiler, in a manner so nearly reversible as to make the whole cycle approximate to the ideal of Carnot.

All this exemplifies the continuous steady pressure of scientific ideas in improving the procedure of the practical engineer. In a different category I would place the invention, by Parsons, of the steam turbine. That, too, was an application of scientific ideas, but it is an example of what I have called a sport. It broke away from established lines, and we may say that in the world of engineering the genius of Parsons opened up a new kingdom. He gave us a power producer wholly novel in action and design, capable of greatly augmented efficiency, with a concentration and magnitude of effect never even imagined before.

Another sport was the internal-combustion engine. Time would fail me to trace its development from primitive forms; to tell of the steps, big and little, but all essentially scientific, which brought into operation the cycles of Otto and Clerk and Diesel; of the multitude of engines which have turned the man in the street into an engineer, crowding the highways, dotting the seas, and achieving in some sense a conquest of the air.

Reverse a heat engine and you have a heat pump, which means that by expending power from outside you can make a body colder than its surroundings and keep it colder. From this simple piece of thermodynamics has sprung a branch of engineering with immense and growing economic importance. Refrigeration makes the

whole world our orchard, our sheep-farm and our cattle-ranch. Perhaps in no other field do so many scientific problems arise for solution as in the transport and storage of foodstuffs under such conditions of cold as will, without substantial damage, preserve them from bacterial attack.

The science of refrigeration, too, offers a conspicuous example of how an industrial process, strikingly novel, may take its origin from an apparently insignificant physical fact, and then repay the debt to pure science by promoting the progress of research. Long ago Kelvin and Joule, in experiments on the properties of gases, discovered that when air escapes under pressure through a throttling orifice it undergoes a small drop in temperature—about one-fourth of a degree for each atmosphere. Years afterwards Linde and others, by applying a regenerative interchanger to transfer the cold from the escaping air to the stream that was approaching the orifice so as to obtain a cumulative effect, used this as a practical means of liquefying air, and of separating its oxygen and nitrogen, with the result that each of the two may be commercially utilized. This is now the foundation of more than one considerable industry ; moreover, it has given to physicists a new tool of research, enabling them to bring temperatures down to an extreme never before reached in any terrestrial laboratory.

In the region of applied electricity, perhaps more than in any other part of engineering, instances multiply themselves of the exchange of benefits between practice and science. One may, of course, say, with perfect truth, that all the applications of electricity are in their origin fruits of scientific research. If you trace, for example, the history of the dynamo, you go back through Hopkinson's formulation of the principle of the magnetic circuit to an experiment of Faraday, which, in 1831, first showed that the movement of a conductor across a

magnetic field generates electromotive force. The very language in which one describes this fundamental discovery is language we owe to Faraday himself. From that experiment what a progeny has sprung! And may it not be fairly claimed that all the practical devices of electrical engineers, the dynamo, the motor, the transformer, the storage battery, the arc lamp, the vacuum bulb, the electrolysis bath, the electric furnace, the telephone, and many more have advanced the purely philosophic study of electricity? With their help the physicists have now discovered that in positive and negative electrification—in the protons and electrons, which together compose the atom—we have the primitive brick-bats of which the whole material universe is built. Perhaps some day the philosophers, who have analysed matter into these brick-bats, teaching us how many of each kind are in the atom of any element, and the engineers, who are always searching for sources of power, may put their heads together and discover a means of tapping, in some sufficiently controllable manner, the huge stores of internal energy which the atoms are known to conceal. That would, indeed, be a new departure, but I dare not predict that it will ever happen. Prophecy, as George Eliot said, is of all forms of human error the most gratuitous.

When Kelvin, in 1853, discovered as a piece of mathematical reasoning that under certain conditions as to resistance, self-induction, and capacity, a discharge of electricity would be oscillatory, he little knew what he was letting the world in for. From that seed has grown a great tree. The branches, one may say, are visible over many house-tops. Through Clerk Maxwell, Hertz, Lodge, Marconi, Fleming, de Forest, and many others, discovery and invention have proceeded, hand in hand, to accomplish what seems to me the most wonderful of all the wonders of applied science. The telephone of Graham

Bell, the microphone of Hughes, the phonograph of Edison were arresting marvels whose first coming I vividly recall. But wireless broadcasting still more impresses the imagination. It gives other marvels an added value, and works an even greater social change.

Towards the end of last century, when physical science seemed to some of its votaries to have settled into a groove, suddenly there was an astounding outburst of discovery. The X-rays, radioactivity, the electron—these followed one another in bewildering succession ; discoveries wholly unexpected and pregnant with uses. Each in turn was a revelation to the philosopher ; it gave a fresh direction to his concepts of Nature, and it enriched him with novel methods of research. Each of these discoveries also offered an untrodden avenue of practical application. Let me, in the short time that remains, speak briefly of what engineers have done to harness the free electron.

About 1895 Sir J. J. Thomson, examining the discharge which proceeds from the cathode or negative pole of a Crookes' vacuum tube, established the fact that it consists of a stream of separate particles—corpuscles he called them—of negative electricity, independent and all absolutely alike. These corpuscles are now called electrons ; normally, in the absence of electrical disturbance they make up, as it were, the crinoline or fender of a material atom ; but when streaming from the cathode they have escaped from domestic ties. Each electron is a definite quantity of disembodied electricity—an irreducible unit—delightfully free to respond to any electric force, for its inertia is barely the eighteen-hundredth part of that of the lightest atom of ordinary matter. Free electrons are known to be given out by highly heated substances, such as the glowing filament in the vacuum bulb of an electric lamp. This fact was turned to account

by Fleming in an invention which one may, with no exaggeration, call epoch-making. He was in search of a sensitive detector of wireless signals, a detector more sensitive than the types Marconi originally employed. When a telegraphic signal sent by wireless strikes the receiving aerial it sets up a group of electrical oscillations, where crests and hollows alternate in very rapid succession—many thousands of times per second. To get them to make a signal which will be heard on a telephone or shown by a galvanometer, you must rectify the group, cutting out the hollows, one may say, and leaving only the crests. Fleming, in 1905, had the happy inspiration to employ the electrons which are given off by the hot filament in a vacuum bulb as agents in the work of rectification. For this purpose he fitted the bulb with a second conductor, now called the plate or anode, to which the stream of electrons from the hot filament may pass. He connected the bulb with the receiving aerial in such a manner that oscillations due to the wireless signal endeavoured to bridge the gap between filament and plate. When this is done, the crests—as we may call those parts of the oscillating current which flow *with* the stream of electrons—pass easily; but the hollows, which are the parts that try to flow the opposite way, are stopped. Thus the device acts as a rectifier of the received oscillations, keeping the crests but cutting out the hollows, and for that reason the inventor very appropriately called it a valve—a thing that allows passage only one way.

The Fleming thermionic valve soon came into use as a sensitive detector of wireless signals. Two years or so later its capabilities were much extended by the American electrician Lee de Forest, who introduced a third conductor in the form of a grid through which the stream of electrons passed on their way from the filament to the plate. With this addition the device, now

called a triode valve, could be applied as a powerful relay or amplifier, receiving any electrical oscillations and passing them on, greatly magnified. It is arranged that the incoming oscillations shall cause small variations in the potential of the grid ; these produce large and sensibly proportional changes in the electron stream which passes to the plate. The triode valve is the essential instrument of modern wireless ; it serves not only to rectify and magnify the received signals, but also, at the sending end, to create the oscillations which are radiated into space. Thus, from the great station at Rugby, a group of mammoth triode valves converts hundreds of horse-power into high-frequency electrical oscillations which carry signals to America. Even this is not the end of the wonderful story, for the triode valve also acts as what is called a modulator, impressing upon the high-frequency waves which constitute wireless radiation the fluctuations of amplitude which enable them to serve as carriers of speech or of music, so that they may thereby convey the relatively slow vibrations of quite another sort which make up sound. Further, in telephoning over wires, the triode valve forms an admirably effective relay, acting, at a succession of points along the line, to restore the energy of the transmitted sound without injury to its quality. Moreover, by using suitable ' filtered ' bands of carrier currents, a number of entirely independent conversations can take place simultaneously over the same wire, while it serves also as a channel for a multiple group of telegraphic messages. All these wonders are made possible by the triode valve. Its technical applications appear to have no bounds. It is also an instrument of research ; it can be made to generate vibrations of unexampled frequency, and in the hands of physiologists and others it measures the slightest and most fugitive of electrical effects.

I have cited enough examples to illustrate the broad

truth of Tredgold's dictum that the scope and utility of civil engineering are increased by every discovery in natural philosophy. But so sweeping a statement can scarcely fail to have some exceptions, and exceptions are in fact suggested by the present curious state of physical science. At the moment the very basis of physics is in a state of flux. Its exponents are struggling to assimilate two momentous new ideas—the principle of relativity and the quantum theory. The relation of these ideas to the accustomed body of older physics is obscure. They present dilemmas which are not yet solved. Their exact form and place in the logical scheme of scientific thought has still to be determined. One may say that, while the superstructure remains intact, the philosophical foundation on which it stands is strangely disturbed. Physicists are, as it were, confronted with a difficult but not impossible task ; they have to transfer bodily their elaborate and beautifully coherent building, as a going concern, from one foundation to another, and the new foundation is not quite ready. They are hard at work laying it, laying it indeed so deep that the passer-by cannot see what is going on. When the operation is completed it will be a great achievement. But I do not think it will make much difference to the engineer, for his concern is with the superstructure itself. That will doubtless settle down quite comfortably when the necessary adjustments are made. It will function as well as before, and continue to admit of extensions which the engineers will in due time turn to practical account.

The century we now review is but a petty unit in the multitude of centuries that make up the recorded and unrecorded history of man. By comparison it is a mere fragment of time, yet how big when judged by the changes it has wrought ! If you test progress by the conquest of inanimate nature, then the century now closing finds

no parallel in the past. It may be likened to the efflorescence of a plant which for long has been quietly growing to maturity and suddenly bursts into flower. We have witnessed as it were the change from bud to blossom. What is to follow? What is left for the future engineer to do? When you celebrate the second centenary of this Institution, of what will your lecturer have to tell? Can the recent astounding pace of discovery and invention be maintained? Or does a time approach when engineers will sit down like so many Alexanders to lament a too completely conquered world of mechanical things, just as a time comes to geographers when there are no more regions to explore? Transport, especially by air, may be made less perilous and more convenient. Communication may be extended to include vision; that is half done already, and I confess to no enthusiasm for the other half. Power will certainly be more generally distributed. But can we expect the engineers of the coming century to bring about developments in the application of natural resources comparable to those of the past hundred years? I am, as I said, no prophet, but I doubt it. To me it seems more likely that there will be something of a lull in the revolutionary fervour of the engineer. Social changes—drastic social changes—may be looked for, but not, I think, so directly consequent on new inventions as in the century now ending. Mechanical devices will, of course, be increasingly used, but probably they will become standardized and taken for granted, like the watches we carry. We cannot be surprised if we find interest in them slacken. Improvements will be made, but they will attract little notice, for the things they affect will already be commonplaces of life. It may very well happen that the mental energy of mankind, now flowing so strongly in this channel of ours, will seek and find outlets in other directions. While as engineers

III

PHYSICS AND THE ENGINEER

JULY 1922

IN asking me to give this lecture, the Institute of Physics, if I understand it rightly, wishes to focus attention on the close relation which subsists between physics and engineering ; to acknowledge, as it were, the debt of engineering to physics, and incidentally the debt of physics to engineering ; and by inference to emphasize the importance of a study of physics on the part of engineers.

That the two are closely related is a proposition so obvious as not to need demonstration. We have only to think of what is meant by physics and what by engineering to see a connection of the most intimate kind. For what is engineering but the turning to man's use and convenience of the things which it is the business of physics to understand ? The physicist has to study precisely the same material that the engineer has to apply. Both of them are concerned with matter and its properties ; with electricity, which in its ultimate analysis is the stuff of which matter is made ; with energy in its protean changes, with its laws of conservation, transformation, dissipation. Any attempt to turn to practical account the phenomena of matter, of electricity, of energy, presupposes some knowledge of what the phenomena are, of the conditions under which they occur, of the relations they hold to one another. In other words,

any attempt to do the work of the engineer implies some acquaintance with the broad principles of physics. To carry out the routine work of engineering may indeed require little more than a bowing acquaintance with these underlying principles, but the engineer who would leave the beaten track must take physical science for his companion and guide. As the art of engineering progresses, it becomes more and more true that the impulses towards any new departure are in general given by men who are physicists as well as engineers—who are at home in that delightful country which may be described as the border-land of physics and engineering. The borderland is a large country of uncertain area and inconstant allegiance. I have roamed in it for many happy years and have been privileged to know some of the great men who have dwelt on its hill-tops. I have enjoyed its morning mists and its changing landscapes. It would be futile to attempt the drawing of a line between physics and engineering. Should a Boundary Commission ever be appointed, I for one would decline to serve.

If you would learn about the borderland, consult the new *Dictionary of Applied Physics*. In that comprehensive publication Sir Richard Glazebrook has supplemented the services which he rendered to engineering as head of the National Physical Laboratory during its development from infancy to a vigorous maturity, by another service scarcely less conspicuous. He has given to engineers what is virtually an epitome of their own subject viewed on its scientific side; nowhere, I think, will they find a better account of the modern basis of engineering practice. And he has given to physicists a mine of information about physical experiments and generalizations which loses nothing of its value in the fact that what they would call the pure metal is found with this engineering alloy. Thanks to Sir Richard's skilful

architecture, the palace of the abstract gains by its foundation in the concrete.

There are three main ways in which the study of physics may and does profoundly influence the development of engineering. The first is when a knowledge of physics determines the immediate creative work of the engineer. Inventions are made by men who are able to bring that kind of knowledge to bear on the solution of a practical problem. Here I use the word invention in its widest sense. It may be an invention of the distinctive sort that opens the way to a new world of industrial usage, or it may be no more than a minor feature of design which increases the efficacy of an already common appliance, a product such as comes from the continued application of the trained critical sense of the engineer to the results of his experience, when that sense has been sharpened by the habit of giving the results of experience a scientific interpretation. Or it may be anything between these extremes : in all inventions and designs there is room for the application of physical science, and in most inventions and designs you find it has been operative. That is one of the three chief ways in which physics affects engineering.

Another way is when the physicist himself makes an advance in the principles of his science of such a nature as to illuminate the operations of the engineer, systematizing what before was haphazard and vague, clarifying the ideas and directing the efforts of the practical man, sometimes by showing him what is impossible, sometimes by revealing possibilities that are not yet fully explored. It is mainly by such steps that the theory of engineering progresses.

Under this head also we may class the service that physics does to engineering when it devises methods of exact testing and supplies instruments for that, or when it prescribes units and establishes standards which are

useful for engineering measurements and calculations. Much of what is now done in the National Physical Laboratory comes into this category. A conspicuous early example of this kind of service was the settling of electrical standards, mainly the work of a committee of physicists, some of whom, like Kelvin and Fleeming Jenkin, were alive to the immediate needs of telegraphy. Here, indeed, we have a notable example of the benefits that engineering has done to physics, as well as those that physics has done to engineering. Undertaken largely with a practical motive, the determination of the electrical standards not only met the urgent needs of the telegraphists and laid a foundation for the later development of electrical engineering in regard to light and power, but it also reacted most beneficially on physics, by giving a new precision to research. Another example is the determination of the mechanical equivalent of heat, first by the labours of the great pioneer Joule, and afterwards by many others, among whom I would specially mention Osborne Reynolds, a worker of genius to whom all engineers are lastingly grateful, not only for this service, but for his illuminating examination—experimental and mathematical—of many engineering problems, especially in hydrodynamics. No better examples could be given of the clarifying type of physical investigation than his inquiry into the nature of fluid friction, which formulated the distinction between stream-line and turbulent flow, his application of the same principles to explain the process of lubrication, or his discussion of the free expansion of a gas. The theory of engineering owes much to the originality and intellectual thoroughness of Osborne Reynolds. His ideas permeate much of modern practice.

The second head, in fact, includes all contributions to what is comprehensively called the theory of engineering. For the theory of engineering is, in the widest sense,

physics seen through selective glasses, which pick out those parts that are important to the engineer and magnify them—giving them such emphasis and illustration as will enable the engineer to realize their relation to his practice and to apply them in it. The art of engineering includes much that lies outside of formulated theory. The rule-of-thumb plays, and will always play, a useful part. There is an engineering intuition, born of experience and inheriting its gathered store, which reaches conclusions by no traceable process of analysis and ratiocination. Such an instinct is an invaluable possession : it goes a long way towards the composition of a good engineer. But the art of engineering grows constantly more complex, and the need for systematic theory therefore becomes more clamant. The engineer is called upon to occupy province after province outside the range of his primitive experience : he must learn how to argue from the known to the unknown, to direct experiments so that they will yield specific data that are necessary in a particular problem, to plan combinations that will bring about new results. He must understand, distinguish, predict. Let him keep, if he can, his practical instinct in matters of detail. But he will be helpless—increasingly helpless—if he does not also know something of the methods and results of science : if, in a word, he is ignorant of the theory of engineering.

And then there is a third way. It may happen—it has often happened—that the progress of physics affects that of engineering without intention on the part of the discoverer, and without recognition of the practical bearing of the discovery. He would be a rash man who would deny to any discovery in physics the possibility of some day finding practical application, however far it may at first seem from the needs and uses of humanity. When Kelvin, for example, first showed, as a conclusion from

his mathematical study of electricity, that under certain conditions an electric discharge might be oscillatory, richly endowed though he was with the *flair* of the inventor, he little guessed that in the discovery was the germ of a method of diffusing information of literally world-wide applicability, which has added a new word to the popular vocabulary. It appears that 'broadcasting' is about to overwork the ether, just when some disciples of Einstein tell us there is no ether to be overworked. The germ lay dormant till after Maxwell conceived electric waves in space and Hertz detected them ; before it fructified there was much invention to be done by Lodge, Marconi, Fleming, and many more. Even in the details of that invention there were unlooked for uses of physical facts which had been discovered without a thought that they would ever be turned to practical account. The existence of electrons, their power of movement in an electric field, their emission from hot bodies, were physical discoveries apparently remote enough from practice ; but when applied by one who was both physicist and engineer they gave us the Fleming valve, and endowed wireless telegraphy with an organ of perception incomparably more sensitive than it possessed before.

Glance at the history of any branch of engineering, at the achievements of any of the recognized pioneers, especially those who come within the more modern period, and you will see the physicist at work : you will readily trace the influence of scientific knowledge and scientific habits of thought. Sometimes, indeed, you will find the same master-mind contributing in more than one of the three ways I have tried to classify. Take, for instance, a name revered within these walls—that of John Hopkinson. What were the qualities that made him one of the fathers of electrical engineering ? In part, of course, a practical talent without which no engineer is great. But beyond

that, and co-operating with it in the happiest association, he had another gift : he could grasp with rare power and precision a scientific principle and develop its consequences with the easy mastery of the trained mathematician. Some of his inventions are obvious instances of my first category—such as his three-wire system of distribution, or his series-parallel control for electric locomotives. There you have more or less simple results which came about almost inevitably when the skilled thinker brought his scientific knowledge and the logic of his mathematics—albeit in a quite elementary form—to bear on a practical engineering problem which the circumstances of the time put in his way. In a different category stands his formulation of the principle of the magnetic circuit—the relation which he for the first time established between the magnetic flux and the line-integral of the magnetic force round the circuit as a whole, thereby introducing order into what it is scarcely an exaggeration to call chaos, and substituting a methodical treatment of dynamo design for what had previously been little more than empirical guessing. He laid as it were a track through the jungle—a track along which any one might follow. It is in the second category that I would place this service. It was the establishment of a broad principle, illuminating to the physicist, and of fundamental importance in the science and practice of electrical engineering.

In selecting examples of the influence of physicists one's only difficulty is that there is an *embarras de richesse*. The life-work of Kelvin alone would, in this connection, furnish enough material for a whole course of lectures. If in what follows I draw specially on that source, there are two reasons. One is that for many years I knew and loved him as a master. The other is that I have been asked to deal specially to-night with the relation of engineering

to a branch of science which owes perhaps more to him than to any other man—the science of thermodynamics, or to put it more comprehensively, the science of energy.

Kelvin, as you all know, was eminent for his direct services to engineering. His inventions made submarine telegraphy practicable ; they were beautiful examples of what can be accomplished by the deliberate application of scientific reasoning in questions of design. It is not of them, however, I would speak now, but rather of the introduction of those ideas that govern the transformation of energy, and in particular the development of mechanical power through the agency of heat—a branch of engineering which in its immense modern development owes more to our chairman (Sir Charles Parsons) than to any other living man.

When James Watt, in 1765, invented the separate condenser, he had a clear and well-founded appreciation of its physical function in preventing waste, waste of steam and therefore waste of coal. In his own words, his object was to keep the cylinder as hot as the steam that entered it : to avoid the alternate heating and cooling that was a conspicuous defect in the earlier engines of Savery and Newcomen. It was a great step, and another, equally great, was his invention of expansive working, when he shut the connection between the boiler and the cylinder early in the piston's stroke, and allowed the steam then in the cylinder to go on doing work while its pressure fell as the piston continued to advance. To-day we can express the significance of these two inventions in language which Watt would not have understood, by saying that they both went far towards making the action of the engine reversible in the thermodynamic sense. But in those days the very alphabet of thermodynamics was undiscovered ; the most primitive ideas had still to take shape. Nevertheless Watt accomplished what he did

because he was, in the first instance, a physicist, a student of the scanty knowledge then available regarding the properties of steam, and himself an experimentalist who measured the change of volume when water is vaporized, and made independent discovery of the main facts underlying Black's doctrine of latent heat.

Watt's further invention of the indicator supplied a means of determining the work done by an engine; it was customary to express work as the product of a weight by the height through which it was raised, a measure of performance natural enough for engines whose chief employment was to pump water out of mines. But in Watt's time, and for many years after, though his engines came into very extensive use, there was no general recognition of energy as an indestructible entity, or of the fact that when a heat engine did work a corresponding quantity of heat disappeared, though Rumford had demonstrated that heat might be produced in unlimited amount by friction. Watt was aware of the importance of keeping the cylinder hot and the condenser as cold as the condensing water would allow, and to that extent he must have seen that the engine did its work by taking in heat at a high level of temperature and rejecting heat at a low level. It was not, however, till 1824 that the full significance of the drop in temperature was appreciated. In that year a young French officer who had been trained for military engineering in the École Polytechnique, Sadi Carnot, founded the science of thermodynamics by publishing a little book of one hundred and eighteen pages entitled, *Réflexions sur la Puissance Motrice du Feu et sur les Machines propres à développer cette Puissance*, a work no less remarkable for the elegance and simplicity of its method than for the originality and the far-reaching consequence of its contents.

Carnot begins his immortal essay by remarking on the

absence of, and the need for, a theory of the action of heat engines which shall be general in the sense of being independent of the particular mechanism and the particular working substance. He goes on to point out that the steam is only a means of transporting 'caloric', and the caloric passes through the engine from a region where the temperature is high to another where the temperature is low: it is because of this transfer from a hotter to a colder body that work is done. Wherever there is a difference of temperature it is possible to have motive power produced. He proves that the motive power of heat is independent of the agents set in action to develop it; its quantity is determined solely by the temperatures of the bodies between which, in the complete action, the transfer of caloric occurs. He discusses what are the conditions of working which will give the largest possible output of work when the two temperatures are assigned. He introduces the conception of a working substance which returns after a cycle of operations to its initial state in all respects. He describes a reversible cycle of operations, and proves that, for the same supply of caloric, no engine can do more work than an engine in which all the actions are reversible.

This, and more, was established by a chain of reasoning which remains valid notwithstanding the fact that when he wrote the essay Carnot shared the current notion that the 'caloric' passed through the engine without becoming altered in amount.

He died eight years later—a victim of cholera, at the age of thirty-six—without having published anything more. But he left rough note-books from which it is clear that his ideas about the nature of heat had undergone a change. One of his notes runs thus:

'Heat is nothing else than motive power, or rather motion which has altered its form. It is a motion in

the particles of bodies. Wherever there is destruction of motive power there is at the same time production of heat in quantity exactly proportional to the quantity of motive power destroyed. Conversely, whenever there is destruction of heat there is production of motive power. It can be laid down as a general proposition that the amount of motive power in nature is invariable, that it is never, strictly speaking, either produced or destroyed. It changes its form indeed, that is to say, it produces now one kind of motion, now another, but it is never annihilated.'

He goes on to give a numerical estimate of the amount of heat put out of existence in developing a unit of motive power ; the figure does not compare badly with what we now know of the mechanical equivalent of heat.

But these notes—the final legacy of Carnot's genius—were not made public till long after he had died—not till 1878, by which time the doctrine they so clearly formulated had become a commonplace of science. Meanwhile, the principles he had established, the notions of a cyclic process, and of reversibility as the criterion of perfection in the production of mechanical effect, though they passed through a period of neglect, had borne abundant fruit. His ideas were first taken up by Clapeyron, who in 1834 wrote an important Memoir on the Motive Power of Heat, restating and illustrating Carnot's arguments and applying them with excellent effect to find a relation, in what we now call a change of phase, between the heat that is absorbed, the alteration which the volume of the substance undergoes, and the gradient of the pressure-temperature curve. To this we owe it that the work of Carnot was kept alive. The little volume of *Réflexions* had made no splash ; Clapeyron saved it from oblivion, and through his writings it was brought to the notice of men who could discern its value. Among these—chief of them all—was William Thomson, with whom Carnot's principles became

a dominating influence. It gave him, as we shall presently see, inspiration for his own greatest work.

Clapeyron was a mining engineer to whom the practical aspect of Carnot's theory made a particular appeal. It is in Clapeyron's paper that we find for the first time the Carnot reversible cycle exhibited by ideal indicator diagrams, which are drawn both for a gas and for a liquid and its vapour, each with its pair of isothermal and pair of adiabatic lines, in the manner familiar now to all students of engineering. Doubtless it was because Clapeyron was an engineer that he had recourse to this helpful graphic method. But he was also, what all engineers are not, a very competent mathematician, and gave analytical expression to Carnot's principles. He dwelt, as Carnot had himself done, on the value of a large ratio of expansion as providing an effective drop in temperature, and on the thermodynamic loss which results, in the working of a steam engine, from the great unutilized drop between the temperature of the furnace and the temperature of the boiler steam. Here again the engineer comes out ; but here, too, he was only following Carnot, who had made the same points with characteristic precision, and had gone so far as to refer in this connection to a primitive form of internal-combustion engine, introduced by Messrs. Niepce, where combustible dust was injected into a cylinder containing air at atmospheric pressure, and was then ignited. In speaking of that engine Carnot uses the following pregnant language :

' Instead of operating as Messrs. Niepce did, it would seem to us better to compress the air by pumps, making it pass through a completely closed combustion chamber into which the combustible would be introduced in small quantities by a mechanism easy to imagine ; to let it develop its action in a cylinder with a piston or in any other sort of vessel capable of enlargement ; and finally

to discharge it to the atmosphere, or even to let it pass under a boiler in order to utilize its remaining temperature.

'The chief difficulties that would have to be met in this mode of working would be to enclose the combustion chamber in a strong enough envelope, while maintaining the combustion in a suitable state, to keep the various parts of the apparatus at a moderate temperature, and to prevent the cylinder and piston from rapidly deteriorating. We do not believe these difficulties insurmountable.'

For the moment, however, we are not concerned with the development of internal-combustion engines, but with the inception and spread of right ideas about thermodynamics. Before tracing the influence of Carnot on the ideas of Kelvin, we must turn to the work of another great pioneer—James Prescott Joule. Carnot had demonstrated very clearly that an engine does mechanical work by letting heat down from a higher to a lower temperature, and that it is only when the working substance which conveys the heat is caused to expand adiabatically through the whole range of temperature that the greatest possible amount of work is obtained. But in his published writings at least he had failed to see that in the process some of the heat disappears : though he understood fully how work is done by the agency of heat, he missed the fact that it is done through the conversion of heat. And it is noteworthy that all the early users of steam engines missed it too.

Remember however, in extenuation, that the efficiency achieved in those days was very meagre—even in good examples only about 4 per cent. of the heat supplied to the engine was actually converted into work. If an enterprising engineer had attempted to measure, with the means then at his disposal, the heat supplied to the steam and the heat discharged from the condenser, he would have found, after allowing for losses of heat by

conduction and radiation, that the two quantities differed by an amount so small that he might well have put it down to an error of observation.

Thus it happened that the consequences of what is now called the Second Law were discussed and accepted in the science of thermodynamics and in the practice of engineering, before there was any definite recognition of the First Law—before there was proof or even statement of the doctrine of the Conservation of Energy.

That doctrine was established by the experiments and reasoning of Joule, who in 1838, at the age of nineteen, began to describe researches on the production of power by an electromagnetic engine, a motor, that is to say, driven by the consumption of zinc in a galvanic battery. Before long he came to recognize that when the motor was being driven, the heat which would otherwise have appeared in the circuit was diminished by an amount depending on the amount of mechanical work done by the motor, and in this way he arrived at his earliest determination of the mechanical equivalent of heat. As a result of thirteen experiments he states (in a paper of 1843) :

'The quantity of heat capable of increasing the temperature of a pound of water one degree of Fahrenheit's scale is equal to and may be converted into a mechanical force capable of raising 838 lb. to a perpendicular height of one foot.'

His subsequent and more exact measurements were made by other methods, some by the expansion of air, some by the motion of water through narrow tubes, and some by the stirring of water with a paddle driven by the descent of weights. It was in 1847 that he first gave a comprehensive statement of the doctrine of conservation —of the essential indestructibility of all forms of what we now call energy. In the same year, at the Oxford Meeting

of the British Association, he preached the doctrine to an audience of scientific critics, for the most part very incredulous ; and there for the first time he met William Thomson.

Thomson was then a convinced and ardent disciple of the teaching of Carnot, and could not at first reconcile Joule's new idea with the limitation which Carnot's principle set on the production of work by means of heat. He had learnt from Carnot that the capability of heat to produce work depends on the temperature ; that if heat were simply allowed to flow by conduction from a hot body to the cold surroundings its capacity for producing work was lost beyond recall. How then could it be said, as Joule said, that heat, irrespective of any question of temperature, was equal to and might be converted into work ? Here was a perplexity—an apparent contradiction, an obstacle to the reception of Joule's ideas—which it took Thomson several years to overcome. Let us hear the story of that first encounter in Thomson's own words :

' I made Joule's acquaintance at the Oxford meeting, and it quickly ripened into a lifelong friendship. I heard his paper read at the section, and felt strongly impelled to rise and say that it must be wrong, because the true mechanical value of heat given, suppose, to warm water, must for small differences of temperature be proportional to the square of its quantity. I knew from Carnot's law that this must be true (and it *is* true ; only now I call it "motivity" in order not to clash with Joule's "mechanical value"). But as I listened on and on I saw that though Carnot had vitally important truth not to be abandoned, Joule had certainly a great truth and a great discovery, and a most important measurement to bring forward. So instead of rising with my objection to the meeting, I waited till it was over and said my say to Joule himself at the end. This made my first introduction to him. . . . About a fortnight later I was walking

down from Chamounix to commence the tour of Mont Blanc, and whom should I meet walking up but Joule, with a long thermometer in his hand, and a carriage with a lady in it not far off. He told me he had been married since we parted at Oxford, and he was going to try for elevation of temperature in waterfalls. . . .

You must think of Thomson then as a youth of twenty-three. Two years before that he had taken his Cambridge degree and had gone to Paris to make acquaintance with the French physicists and mathematicians. He worked in the laboratory of Regnault, assisting him for a short time in the great series of experiments by which the physical properties of steam and gases were determined. He read the paper of Clapeyron, and searched in vain through the libraries and bookshops for a copy of the essay of Carnot. Polite booksellers would offer him a volume on some social question by Hippolyte Carnot, the brother, or a treatise on fortification by the father—‘the organiser of victory’—but the work of Sadi was quite unknown.

Even in 1849, when Thomson gave to the Royal Society of Edinburgh an account of Carnot’s theory, he was still puzzled by the supposed discrepancy; he speaks of ‘the very perplexing question in the theory of heat by which we are at present arrested.’ It was not till the end of 1850, or early in 1851, that his doubts and difficulties vanished. He then accepted whole-heartedly the conclusions of Joule, recognizing at last that they were really in accord with the principle of Carnot, and that it was only by combining both that a complete theory was to be framed. This he proceeded to do with amazing fertility, generality, and power, passing quickly from point to point, from one field of physical action to another, and flooding all with light. The results appeared in a series of papers, beginning with 1851.

In the previous year it had become apparent to another great thinker that there was no incompatibility between the reasoning of Carnot and the experiments of Joule. This was Clausius, whose development of the subject proceeds on somewhat different lines. Thomson made his argument independent of the properties of any particular substance ; Clausius employed the device, exceedingly helpful to the student, of imagining a perfect gas. We are not concerned here with the apportionment of credit. Both were founders and master-builders ; and there is yet a third whose name is to be placed with theirs as an originator of the science of thermodynamics. That is the engineer Macquorn Rankine, whose independent methods, so individual and imaginative as to be often obscure, nevertheless led him to right conclusions. To him we owe the earliest systematic treatise on the subject, as well as its quantitative application to the steam engine, and among other important contributions the first introduction of the function to which Clausius afterwards gave the name of entropy.

In 1852 Thomson showed that the new ideas pointed to a cosmic result ; that in all transformations of energy there was a loss of availability for further transformation, that the universe was, as it were, in the state of a wound-up clock which was running down. This was the doctrine of the dissipation of energy which Clausius expressed in other language by saying that the entropy of the universe tends to a maximum.

Go back for a moment to the reversible engine of Carnot. Carnot made the mistake of saying that the caloric supplied at a high temperature passed down through the engine without being changed in amount. If he had said 'entropy' instead of 'caloric' the statement would have been true, for in any reversible operation the quantity of entropy which a substance gains or loses is equal to the

heat taken in or given out divided by the absolute temperature, and in Carnot's cycle the quotient Q/T has the same value at the top and at the bottom of the cycle. In a Carnot engine, using steam, the entropy discharged to the condenser would be equal to the entropy taken in from the boiler.

Callendar—a physicist to whom engineers are grateful for many things—has suggested that Carnot really meant what we now call entropy when he said caloric, but I am afraid even my devotion to the memory of Carnot does not allow me to take that view.

This brings us to another point. The principle that in a reversible cycle Q/T is the same for the reception and for discharge of heat shows that Carnot's engine gives a means of defining an ideal scale of temperature, which will be absolute in the sense of being independent of the properties of any thermometric substance such as mercury or air, and will start from a zero which is absolute in the sense that any lower temperature is demonstrably impossible. This absolute or thermodynamic scale was deduced by Thomson from the principles of Carnot as early as 1848, and later he embarked on experiments along with Joule to determine how nearly the absolute scale agreed with the scale of a thermometer working by the expansion of air under constant pressure.

These were the famous experiments in which air was forced under pressure to pass through a porous plug. If there were no change of temperature in the process the behaviour of air would conform to that of the imagined perfect gas, whose internal energy depends only on its temperature. The experiments showed that the agreement was close, but not complete—that in passing the porous plug the air became very slightly colder, about a quarter of a degree colder for each atmosphere of drop in pressure. This is the Joule-Thomson cooling effect,

which many years after was applied by Linde as an effective method of reaching extremely low temperatures and liquefying the most refractory gases. In the hands of Linde, Claude, and others it has become the basis of a great industry, serving to separate the constituents of the atmosphere to provide oxygen for industrial and medical uses, and nitrogen for the manufacture of fertilizers. Here we have a striking example of a recondite and apparently trifling physical phenomenon assuming in time a useful and even prominent place in the world of the engineer.

Linde made the Joule-Thomson cooling effect effective because he made it cumulative, and he did so by applying to it another thermodynamic device—the regenerator, or interchanger, by which the gas on its way to the plug is deprived of heat by being brought into thermal contact with the gas that has passed the plug and is therefore a little colder. Except for practical imperfections this exchange of heat is a reversible process, and consequently involves no dissipation of energy. Almost simultaneously the same method was suggested independently of Linde by another inventor, Dr. William Hampson.

The conception of a regenerator is one of the oldest in thermodynamics. It dates from 1816: its author was a Scottish minister, the Rev. Robert Stirling, who with his brother James applied it soon after that in an engine which worked by the alternate heating and cooling of a confined quantity of air. The Stirling regenerator was in effect an enclosed channel loosely stacked with material having a large capacity for heat. When hot air was passed through this channel in one direction it deposited its heat, and when the air was passed back it picked the heat up again, almost without loss. In the Stirling engine this device was introduced between the hot and cold ends, with the result that in the cycle of operations the high

and low temperature (isothermal) stages at which heat was received and rejected were separated by two regenerative processes in which the temperature of the working air was caused to fall and to rise. That was years before Carnot, and if Carnot had known of the Stirling engine he would have recognized in it a material embodiment of his own ideas, but with the regenerator acting as a substitute for his adiabatic expansion and compression. It is, in fact, the only possible alternative—the only other way of obtaining a reversible cycle.

Much later, in the hands of Frederick Siemens and his brother William—another brilliant example of the blend of physics with engineering—the regenerative method served to make economically possible the high temperature of the modern steel furnace. Thus we find it to-day working at both extremes of the scale, supplying metallurgists with their hottest infernos, and bringing chemists like Dewar and Kamerlingh Onnes to a paradise within two or three degrees of the absolute zero. Even there they are not perfectly content. ‘The little more and how much it is ; the little less and what worlds away.’

Refrigeration, the commercial process which secures our food supply, is a direct offspring of science, and at every stage of its development the influence of physical ideas is apparent. As early as 1847 Thomson suggested that a Stirling engine, if it were driven through its cycle backwards by spending work upon it, would act as a heat pump, and might be applied to make ice. This idea was reduced to practical form in 1862 by Kirk. The earliest permanently successful refrigerating machines were reversed air engines, working in a manner suggested by Thomson in 1852 and realized by Giffard, Coleman, and others more than twenty years later. They were, so to speak, only roughly approximate Carnot engines ; they followed what is now called a Joule cycle and were com-

peled to work in the reversed fashion, so that the 'caloric', as Carnot would say, was pumped up from the bottom to the top of the cycle. And when in place of air some fluid such as ammonia came to be used, which passed from vapour to liquid and back to vapour in the course of the operation, the reversed Carnot cycle was followed, save that for the stage of adiabatic expansion there was substituted a throttling process in which the Joule-Thomson cooling effect (which is relatively large when the substance throttled is a liquid or a wet vapour) served as the step by which the working fluid passed from its upper to its lower level of temperature. This was a deliberate departure from reversibility : it meant sacrificing a small part of the ideal refrigerating effect, but it was justified because it made the machine simpler and more practically workable.

At the present day there is no branch of engineering in which the guidance of physical principles is more readily accepted and more closely followed than it is in the practice of refrigerating engineers, who make a continuous appeal to the results of research not only in thermodynamics but in thermal insulation, convection, radiation, hygrometry, as well as a whole range of biological questions that lie outside the province of our survey. As an instance, I recall how, many years ago, while visiting the London office of a well-known refrigerating engineer, I first made acquaintance with the Mollier diagram of Entropy and Total Heat. He was using it for the purpose of design, though it was then a scientific novelty which had not yet found its way into any of the text-books.

The history of the internal-combustion engine affords many examples on which there is no time to speak. Carnot demonstrated the advantage of an extended range of temperature—of a high upper limit, and a large ratio of expansion. He pointed out that internal combustion

was the way to secure this, and that there should be much initial compression of the working air. But to imagine an efficient internal-combustion engine is one thing ; to materialize it is quite another. The problem bristles with difficulties that could scarcely have been foreseen by any theorist. Historically the development of gas engines and oil engines has been a prolonged struggle with mechanical obstacles. The broader scientific issues were more or less taken for granted ; the inventors had to concentrate on what one may call the barbed wire that hindered their advance.

To give the Carnot cycle working reality was seen to be impracticable—though at one period Diesel did, I think, aim at that—and the successful engines of modern times embody compromises which, though far short of the ideal, achieve high efficiency. No discussion of these compromises can be attempted here. I pass from the subject with the remark that if you want to study it, you will find it set forth in the writings of my friend Sir Dugald Clerk, himself a notable inventor and practitioner, as well as an exponent of the physical principles that govern the thinking and the practice of the internal-combustion engineer. And in passing I would pay a tribute to the labours of a joint body of engineers and physicists over which he presides, the British Association Committee on Gaseous Explosions. One of their most active members was Bertram Hopkinson, whose experimental studies have taught us much about the nature of explosion, and whose untimely death was a grievous loss alike to science and to engineering.

The internal-combustion engine made aviation possible, and in every advance of that new art, in every feature of its appliances, the influence of physical experiment and mathematical interpretation is admittedly paramount. But it is not for me to speak of these. To men of my

generation the word 'flight' was a convenient metaphor. To the young men of the present it is a stern reality, a glorious experience. Do they realize that their wings began to be shaped through the chrysalis toil of the early fathers of hydrodynamics?

Come back, before we close, to Steam and the Steam Engine. Engineers owe their knowledge of the properties of steam primarily to the researches of Regnault—a prince of physical experimentalists. Later came other contributions by theorists, new mathematical ways of expressing the properties of any fluid, which have proved of immense service in fixing the ideas of engineers and facilitating their calculations. Besides the familiar notions of pressure, volume, temperature, and internal energy, we now employ other functions of the state of a substance (or of a system)—quantities that are definite in any one state and do not depend on the manner in which that state has been reached, quantities which, for that reason, appear in thermodynamic equations as perfect differentials. We have the entropy, which may be defined as that quantity which does not alter when a fluid is adiabatically compressed or expanded; the 'total heat', which is the quantity that remains constant during throttling; and two more—the 'potentials' of Willard Gibbs. One of them is a quantity which remains constant during any change of phase at constant pressure. I wish we had a short name for that—perhaps we might call it the *Phase-Function*. The other is a quantity that remains constant at constant temperature when the change is such that no work is done. This last is what Helmholtz called the 'free energy': it concerns the chemist more than the engineer: you will find it useful if you want to understand the action of the galvanic cell. The 'total heat' is a function of particular importance in engineering, for when steam is caused to enter an engine at a constant

pressure and then expands adiabatically to a lower pressure, and is finally discharged at that pressure, the fall in its total heat—what we now call the ‘heat-drop’—measures the whole work which it does. Hence tables of the ‘heat-drop’ are prepared for the use of engine designers, especially designers of turbines : they show the greatest amount of work ideally obtainable from each pound of steam, under given conditions of admission and exhaust, and it is a simple matter to judge, having regard to experience, what fraction of that is likely to be actually obtained, and so to plan the proper size of the steam passages, and the dimensions and velocity of the blades. It is thanks to mathematical and experimental physicists that the process of steam-turbine design has now become an almost exact science.

For such data engineers owe much to Callendar. His characteristic equation for steam, along with certain results of experiment, has enabled him to calculate tables of values of all the required functions throughout the useful range, values that are thermodynamically consistent with one another—giving the figures a precision and completeness no earlier tables approached. He has rationalized features that were in seeming contradiction : he has taught us, for example, how it is that when steam escapes from a nozzle the discharge is observed to be greater than the old theory led us to expect ; it is because of super-saturation, and this has to be taken account of in framing a correct theory of the steam turbine.

I have touched, but only incidentally, on the theory of the steam turbine. My whole lecture might well have been devoted to the invention of the turbine as a triumphant example of what the engineer may achieve when he is also a physicist. How is it that Sir Charles Parsons has revolutionized steam engineering ? Very simply : the greatest efforts of genius are simple. He has brought

Carnot's engine to reality: or rather he has brought reality nearer to Carnot's engine—not all the way, but nearer. It has been a long journey, a hard labour, but always towards a calculated end. I once saw him carrying sacks of coal with his own hands into the little stokehold of the *Turbinia* so that there should be no delay in beginning an important trial. It was typical of the man. He has never spared himself. He has been carrying heavy sacks all his life; always knowing where to carry them, what was in them, and what was to be got out. The force, the courage, the resolution that were needed for a task such as this have been sustained by imagination and by faith—faith in the logic of his own scientific method.

The reciprocating engine, for all the improvements of Watt and his successors, remained in two conspicuous respects very far short of the Carnot ideal of reversibility. In the first place, there was still periodic interchange of heat between the steam and the metal; some of the steam was condensed as it entered the cylinder, because it found the metallic surfaces chilled by the previous exhaust, and this in its turn was re-evaporated, chilling the metal again before the next admission. In the second place, the steam could not be effectively expanded down to the lower limit of pressure which was determined by the temperature of the condensing water, for its volume in the later stages would have become so great as to make the engine unworkably bulky in proportion to the power, and the friction of the piston would have more than swallowed up the work done by the steam in these later stages. Hence it was unavoidable in practice to release the steam before extracting from it anything like the whole of its ideal content of available work. Both these defects made the action far from reversible. Both were removed by the invention of the steam turbine. In the

turbine there is no alternate give and take of heat, because each part of the metal is continually in contact with steam of one temperature. And in the low-pressure stages there is no preventive friction, nor is the bulk excessive : so advantage may be and is in fact taken of nearly the whole heat-drop. It is true that the internal friction of the fluid comes in as another source of loss, but on the whole the turbine comes much nearer to reversibility. It has also allowed power to be developed on a far larger scale, by single units of mechanism, than was possible before. That was another of the inventor's deliberate aims.

There has lately been a fashion—doubtless a passing fashion—in several departments of thought, to disparage the work of the Victorians. It is the last thing that any one will be disposed to do who studies the development and application of physical science during the nineteenth century. There were giants in those days. There are giants still. The present age is witnessing a wonderful efflorescence in physics : we older students are somewhat bewildered by the strangeness, the boldness, of the ideas that are tumultuously crowding in. It is not easy for some of us to become familiar with electrons and nuclei and atomic structure, with quanta and relativity, with the mutual convertibility of energy and mass. I like to think that these new conceptions and new discoveries will in time find their places in an ordered scheme, and in their turn will inspire the engineers whose business it will be to minister to generations yet unborn.

IV

POWER

AN ADDRESS BY THE PRESIDENT OF THE ENGINEERING SECTION, AT THE CENTENARY MEETING OF THE BRITISH ASSOCIATION, LONDON, 1931¹

IT is perhaps right to warn you at the outset that this is an attempt to kill two birds with one rather large stone. The address has to serve a double purpose. Besides being the usual offering to convention which is expected of the President of a Section, it has the responsibility of being a Thesis, delivered in fulfilment of a trust which was undertaken by the British Association many years ago. The thesis has a prescribed theme. So instead of being free, as presidents of sections generally are, to choose any text, or none, I find a text ready chosen for me. It is taken, as you will presently see, from one of the prophets. Not one of the minor prophets, for the prophecy about which I have to speak was uttered by Sir Frederick Bramwell. Nobody who is old enough to recall Bramwell's commanding presence, his generous proportions, his patriarchal air, his pleasant acceptance of acknowledged leadership, will ever think of him in terms such as the word 'minor' would imply. Fifty years ago he was Pontifex Maximus in the world of engineering,

¹ The late Sir Frederick Bramwell in 1903 made provision for the preparation of a thesis or lecture 'dealing with the whole question of the prime-movers of 1931, and especially with the then relation between steam engines and internal-combustion engines,' to be given at the Centenary Meeting. This Presidential Address to Section G (Engineering) is the lecture thus ordained by Bramwell.

not because he built bridges but because he spoke with almost papal authority. An opinion by Bramwell could do much to make or mar any enterprise. To-day we have to discuss a forecast which he offered at the Jubilee meeting of this Association, a forecast to which he and his contemporaries attached particular importance. We must now assign to it a place in the long list of prophecies that have turned out to be overstatements ; nevertheless, it deserves attention not only as an item in the history of mechanical science, but because in the light of present-day experience we recognize how much there was in it of the vision of truth.

It deals with a subject that is appropriate for a presidential address to Section G. The president of this section cannot but be conscious that he is addressing an audience larger than a mere group of engineering experts. Beyond the strictly professional circle is a fringe, and beyond the fringe a vague and mobile auditory of persons who take a lively interest in engineering questions, whose knowledge, so far as it goes, is real and practical. Among the triumphs of applied science is this, that it has transformed the man in the street into a sort of engineer. Society has been mechanized : the noise, the fuss and unrest of the workshop are become a part of normal life. The language of the expert is no longer his own shibboleth ; it has been taken into the stock of common speech. A little knowledge used to be called a dangerous thing ; now we all have it and are content—or at least obliged—to live dangerously. I need not enlarge on a point of which everybody is well aware. But for myself it carries this lesson, that in speaking from the Chair of the Engineering Section I am now, so to say, broadcasting to a multitude of intelligent amateurs. I hope the experts will forgive me if in what I say they find nothing that is not already familiar. I shall try to speak plainly to the plain man.

more than the internal-combustion engine to make obsolete the Victorian attitude to life. Between the two classes of heat engines there is a rivalry ; one might almost say a sort of war. Each has fields of operation where its supremacy hardly admits of doubt, but there are disputed regions in which we find a lively contest. As sporting critics we must recognize the merits of both combatants. Here, surely, is a suitable subject for an address from one who is old enough to remember patting the rivals on the head when they were boys. He now draws up his chair, taking care not to put it too near the ropes, and proceeds to make such comments as he may about the game.

A quarter of a century ago I presided over Section G, and now the honour is unexpectedly repeated. It would seem that the Council's policy in this happy centenary is to trot out some of the veterans, for the entertainment, let us hope, of less fallible youth. Before asking me to act as President of the Section, they had invited me to give the Bramwell Lecture, and I could accept the two duties only through their kindness in allowing one address to serve for both.

To explain the task of the Bramwell Lecturer we must recall the meeting of 1881, when the Association was celebrating its Jubilee in the heyday of Victorian prosperity and confidence. It was a jubilant Jubilee. Never, perhaps, was applied science more actively progressive. From day to day its achievements compelled attention. Electricity was knocking at the door, bringing a wallet big with gifts, wonderful gifts that established new contacts between the sciences of the laboratory and the arts of social life.

The world of invention was in a ferment ; the brew was seething and bubbling. Some of the froth on the surface had to be blown away, but beneath that there

People who have a preference for the unintelligible will, no doubt, be able to gratify it in at least one other Section.

What has mechanized the world is, more than anything else, the production and the distribution of power. To-day we are concerned with the best ways of converting the heat of combustion of fuel into mechanical or electrical energy. One need draw no distinction in this regard between mechanical and electrical forms of energy, for each may be converted into the other almost without loss. But to get either from heat is another story. At the utmost you can convert no more than a modest fraction of the heat that comes from fuel : in specially favourable cases you may hope to convert something like a third ; the rest is scattered beyond recall. How to effect this conversion, through the agency of a heat engine, is a matter of perpetual interest to engineers. In assessing the merits of the engine they have to think not only of its *efficiency*—that is the fraction of the heat which it succeeds in converting—but also of other characteristics which are scarcely less important : of its fitness for particular types of fuel, its convenience and ease of driving, its reliability, its endurance, its bulk, its weight, its cost. The heat engines with which we are practically concerned divide themselves into two great classes. First, there are those which use steam for working substance, whether of the reciprocating or turbine type ; in them the heat of the burning fuel is generated outside and has to make its way to the working substance through a containing shell. Second, there is the internal-combustion class where the heat of the fuel is generated within the working substance itself. To this class belong the gas, oil, and petrol engines that have sprung into existence within the memory of many persons now living and have profoundly changed our habits and our outlook. Nothing perhaps has done

more than the internal-combustion engine to make obsolete the Victorian attitude to life. Between the two classes of heat engines there is a rivalry ; one might almost say a sort of war. Each has fields of operation where its supremacy hardly admits of doubt, but there are disputed regions in which we find a lively contest. As sporting critics we must recognize the merits of both combatants. Here, surely, is a suitable subject for an address from one who is old enough to remember patting the rivals on the head when they were boys. He now draws up his chair, taking care not to put it too near the ropes, and proceeds to make such comments as he may about the game.

A quarter of a century ago I presided over Section G, and now the honour is unexpectedly repeated. It would seem that the Council's policy in this happy centenary is to trot out some of the veterans, for the entertainment, let us hope, of less fallible youth. Before asking me to act as President of the Section, they had invited me to give the Bramwell Lecture, and I could accept the two duties only through their kindness in allowing one address to serve for both.

To explain the task of the Bramwell Lecturer we must recall the meeting of 1881, when the Association was celebrating its Jubilee in the heyday of Victorian prosperity and confidence. It was a jubilant Jubilee. Never, perhaps, was applied science more actively progressive. From day to day its achievements compelled attention. Electricity was knocking at the door, bringing a wallet big with gifts, wonderful gifts that established new contacts between the sciences of the laboratory and the arts of social life.

The world of invention was in a ferment ; the brew was seething and bubbling. Some of the froth on the surface had to be blown away, but beneath that there

were changes in substance which fifty years have strengthened and matured.

Think for a moment of what the late seventies and the early eighties gave to mankind. The telephone, the phonograph, the incandescent lamp, the dynamo in a practical form, the electric motor, the storage battery, the transformer, the internal-combustion engine using liquid fuel, cold-storage and refrigerated transport of food, the idea of public electric supply, the use of alternating currents, the first clear recognition of the potentialities of electricity as an agent for lighting, for traction, for the conveyance and distribution of power. There, indeed, was a dish to set before the potential rulers of a kingdom which was waiting to be explored, where every engineer in the bud might well fancy himself to be a coming king.

Bliss was it in that dawn to be alive,
But to be young was very heaven.

Looking back now, it is curious to reflect how poor was the equipment of most of the pioneers. There were, indeed, a few great leaders—a Kelvin or a Hopkinson—who possessed the right kind of basic understanding, who could turn to theory for guidance and had the engineer's instinct to give it application. Here and there was a Ferranti, with vision and imagination to compensate for the lack of formal knowledge. But most of the zealous workers of those days were empirics, full of enterprise and enthusiasm and not much more. They could get little help from text-books. Some of them made what may now seem strange mistakes, and in that way they acquired a costly education.

Among those fertile years I would specially mention 1881, which was the date of Bramwell's prophecy as well as the Jubilee of the Association. Apart from that it

marks an epoch. For the world then realized that a problem was at last solved with which it had been much concerned, the problem called the subdivision of the electric light. Before that the electric light had meant the electric arc—a dazzling unit, brilliant, overpowering, capricious, admired out of doors, but quite unfitted for the home. It was a tiger burning bright which declined to become a domestic pet.

Then came Edison and Swan who, working separately, taught us how to tame it by inventing the incandescent filament enclosed within a vacuum bulb. Near the end of 1881 Sir William Thomson (as he then was) lighted his house in Glasgow by means of Swan's lamps, using with them a storage battery of Faure's cells, the advent of which had been hailed with enthusiasm and had raised unduly high hopes. For prime-mover he chose the new gas engine of Dugald Clerk which completed its cycle in two strokes, unlike the already familiar Otto engine, which required four. Clerk's engine was itself a novelty the importance of which we have come to recognize. To this day all internal-combustion engines use either the Clerk or the Otto cycle, and for large powers the Clerk cycle has advantages which tend to give it the favoured place.

Fifty years ago the gas engine was much in the public eye. It had already proved its value in many workrooms. There was still no supply of electricity from public stations, and for a private installation the gas engine furnished a suitable and exceedingly convenient source of power. It was a day of small things; an engine which developed as much as 20 horse-power was described as a 'king of gas engines'. Within this modest limit the Otto engine, which dates from 1876, had a well-deserved reputation as an efficient and trustworthy prime-mover that would run with little attention, using ordinary town gas as its fuel.

At the Jubilee meeting of this Association Emerson Dowson drew attention to a less costly alternative : he had made what was called producer gas from coke or anthracite, and had run engines with it. He had even demonstrated that with Dowson gas you could get a horse-power from 1 lb. of coal per hour, instead of burning 2 or 3 lb. at the very least, as you had to do in a steam engine. From this it was clear that the gas engine offered immensely attractive possibilities as a generator of power.

Even before 1881 engineers were busy with efforts to improve its efficiency. Fleeming Jenkin, my teacher and professional chief, was struggling to apply to it the regenerative methods of economizing heat which Stirling originated in his air engine a century ago—methods which in the meantime had revolutionized other industries, notably the manufacture of steel. No engineer who gave the matter serious thought could fail to see the advantage of having heat developed within the working substance itself instead of being conveyed to it by conduction through a containing shell ; it was, in fact, the failure of the containing shell that ruined Stirling's engine. Another obvious merit of internal combustion was one that Carnot had recognized in the immortal little treatise where he laid the foundations of thermodynamics—the advantage, namely, which you secure by supplying heat to the working substance at a much higher level of temperature than can be reached with steam. Finally, there was this broad difference : the gas engine had the indefinite promise of youth ; the steam engine was an old servant whose limitations were well known. Nobody expected that steam would change its ways. Small wonder, then, that the engineers of those days looked to the future of the gas engine with exaggerated hope.

It was in that spirit that Bramwell made the prophecy we have now, after fifty years, to review. The occasion,

as I have said, was the Jubilee meeting of this Association, held at York in 1881. The President of Section G was Sir William (afterwards Lord) Armstrong. His address was mainly on other subjects, but incidentally it contains an exceedingly apt criticism of the steam engine as they knew it then. He said : ' In expanding the steam we quickly arrive at a point at which the reduced pressure on the piston is so little in excess of the friction of the machine as to render the steam not worth retaining, and at this point we reject it. In figurative language, we take the cream off the bowl, and throw away the milk.' I shall show later that in the modern use of steam we no longer have to cry over the spilling of milk to which Lord Armstrong referred.

After the President had spoken, Bramwell also gave an address, ' On Some of the Developments of Mechanical Engineering During the Last Half Century,' which is printed *in extenso* in the Report. It reviews a great field with the lucidity of which he was a master, dealing specially with applications of the steam engine, and it includes a section relating to the transmission of power. Electrical transmission is barely touched on : it had, in fact, scarcely begun ; but he speaks of transmission of power by means of gas, and in that connection he remarks :

' I think there is a very large future indeed for gas engines. I do not know whether this may be the place wherein to state it, but I believe the way in which we shall utilize our fuel hereafter will, in all probability, not be by way of the steam engine. Sir William Armstrong alluded to this probability in his address, and I entirely agree—if he will allow me to say so—that such a change in the production of power from fuel appears to be impending, if not in the immediate future, at all events in a time not very far remote : and however much the mechanical section of the British Association may to-day

contemplate with regret even the more distant prospect of the steam engine becoming a thing of the past, I very much doubt whether those who meet here fifty years hence will then speak of that motor except in the character of a curiosity to be found in a museum.'

The view expressed by Bramwell in this remarkable forecast found support in more than one quarter. In the following year Sir William Siemens was President of this Association. After acknowledging the great service which the Association had done to engineering by settling a consistent and practical system of electrical units, and himself suggesting that the unit of electrical power in that system should be called the Watt, he went on to compare the theoretical efficiencies of steam engine and gas engine on the basis of the theory of Carnot, and then remarked :

' Before many years we shall find in our factories, and on board our ships, engines with a fuel consumption not exceeding 1 lb. of coal per effective horse-power per hour, in which the gas-producer takes the place of the somewhat complex and dangerous steam boiler.'

Again, the late Lord Rayleigh, speaking from the Presidential Chair at the Montreal meeting of 1884, says:

' The efficiency of the steam engine is found to be so high that there is no great margin remaining for improvement. The higher initial temperature possible in the gas engine opens out much wider possibilities, and many good judges look forward to a time when the steam engine will have to give way to its younger rival.'

Let me quote one more authority. Fleeming Jenkin, lecturing on Gas and Caloric Engines at the Institution of Civil Engineers, in February 1884, refers to the fact that Cowson gas even then allowed the gas engine to compete favourably with the steam engine, and concludes :

* Since this is the case now, and since theory shows that

it is possible to increase the efficiency of the actual gas engine two and even threefold, the conclusion seems irresistible that gas engines will ultimately supplant the steam engine. The steam engine has been improved nearly as far as possible, but the internal-combustion gas engine can undoubtedly be greatly improved, and must command a brilliant future.'

Bramwell himself returned to the question when President of the Association in 1888. In his address from the Chair he repeated the forecast of 1881 with a qualifying phrase or two :

' At the York meeting of our Association I ventured to predict that unless some substantive improvement were made in the steam engine (of which improvement, as yet, we have no notion) I believed its days, for small powers, were numbered, and that those who attended the Centenary of the British Association in 1931 would see the present steam engines in museums, treated as things to be respected, and of antiquarian interest to the engineers of those days, such as are the open-topped steam cylinders of Newcomen and Smeaton to ourselves. I must say I see no reason after the seven years which have elapsed since the York meeting, to regret having made that prophecy, or to desire to withdraw it.'

It is evident that Bramwell took his ' prophecy ' very seriously. He was the acknowledged sage and spokesman of the engineering profession, occupying, in that regard, a unique position, such as no one could possibly hold in the more complex conditions of to-day. He was a humorist, and doubtless there was a conscious touch of humorous exaggeration in what he said. But for all that, it was an engineering judgment delivered *ex cathedra*, and his judgments were accustomed to command respect.

Finally, in July 1903, when within a few months of his death at the age of eighty-five, he wrote as follows

to the President of this Association. After quoting the words he had used at York twenty-two years before, he proceeded thus :

' In saying this, no doubt, I then thought I was speaking somewhat hyperbolically, but from the close attention I have paid to the subject of internal-combustion engines, and from the way in which that attention has revealed a continuous and, year by year, a largely increasing development of such engines, I feel assured that although there may still be steam engines remaining in work in 1931, the output of steam engines in that year will be but small as compared with the output of internal-combustion engines.'

He added that he wished to keep alive the interest of the Association on this subject, and for that purpose offered a sum, which was to be invested in Consols, and in 1931 was to be paid as honorarium

' to a gentleman to be selected by the Council to prepare a paper having my utterances in 1881 as a sort of text, and dealing with the whole question of the prime-movers of 1931, and especially with the then relation between steam engines and internal-combustion engines.'

That is the task I am now attempting to discharge. You do not need to be told that the prediction has, in great measure, failed to come true.

his prophetic outlook. It was more than bold ; it was almost foolhardy. Remember that he had nothing to go by except the performance of the gas engine, and that only in very small powers. Gas, whether the ordinary illuminating gas distilled from coal, or the cheaper product of the Dowson process, was the only fuel then in practical use for internal combustion. The oil engine, in its various forms, the petrol engine, the Diesel engine—these were still to come.

The gas engine itself did not develop so fast as those who had faith in it might have hoped. Sir Dugald Clerk, whose invention of the two-stroke cycle was followed up by many other important services to internal combustion, and who has become its historian, tells us that even in 1898 the largest gas engines then built indicated 220 horse-power. By that time, however, B. H. Thwaite had demonstrated that the so-called waste gases of the blast furnace were a suitable fuel, and this led makers, especially on the Continent, to take up the design of large gas engines in forms which for some years had a conspicuous vogue. There were examples in which as much as 2,000 horse-power was developed in a single cylinder working on the Clerk cycle, and a four-cylinder engine was built to indicate 8,000 horse-power. Such engines were notable for their great bulk and weight. They were also, for the most part, costly failures. The big cylinders, cylinder-heads, and pistons were apt to crack. The difficulty of controlling the temperature of the metal and escaping effects of unequal expansion stopped the construction of gas engines with large cylinders. Moreover, apart from that check it soon became clear that the chief advance of internal combustion was to take place on different lines, namely, by having oil serve as the internal fuel. Gas still plays a useful part, but quite definitely a minor part. The builders of gas engines have wisely sought

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That is the task I am now attempting to discharge. You do not need to be told that the prediction has, in great measure, failed to come true. Steam is neither dead nor dying. On the contrary, its use has immensely developed both on land and sea. To-day, it is a much more efficient medium than it was for the conversion of heat into work, and you find it actuating engines of vastly greater individual and aggregate power than any that were even imagined when Bramwell spoke. But alongside of that we have wonderful achievements on the part of the internal-combustion engine which go far to justify the enthusiasm that stirred him fifty years ago.

Looking back now, one is amazed at the boldness of

his prophetic outlook. It was more than bold ; it was almost foolhardy. Remember that he had nothing to go by except the performance of the gas engine, and that only in very small powers. Gas, whether the ordinary illuminating gas distilled from coal, or the cheaper product of the Dowson process, was the only fuel then in practical use for internal combustion. The oil engine, in its various forms, the petrol engine, the Diesel engine—these were still to come.

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security by restricting the dimensions of their cylinders, and confidence in their wares is now restored. Their products have a well-established and considerable market. But nowadays when we would treat of what internal combustion has accomplished, and of its future, we turn not to gas engines but to engines which use liquid fuel. We think instinctively in terms not of gas but of oil, using that word to include not only the 'heavy' petroleum of the Diesel motor, but the more volatile constituents with a lower flash-point, which in this country go by the name of petrol.

The success of the Otto gas engine led makers to design engines operating in much the same way, but using for fuel a spray of oil instead of gas. Such engines found a place where gas was not available, as in the driving of agricultural machinery. For the most part their fuel was the safe and familiar oil of the paraffin lamp. Like the gas engine, they were heavy and they ran at very moderate speeds, such as 200 revolutions per minute. About 1883 Daimler set himself to produce an engine with much lighter working parts which should run at a far higher speed, five times as fast, or more, and should use for fuel an oil so volatile that a carburettor would serve to charge the incoming air with combustible vapour. After successful trials with a bicycle, he applied his motor, in 1887, to drive a car on the road. That was the beginning of a new era in locomotion. The world discovered in Daimler's petrol engine an appliance such as it had not possessed before—a light, convenient, inexpensive prime-mover, yielding amounts of power which were ample for road vehicles, easy to start and stop and regulate, demanding little attention and no particular skill. Before long it gave city streets an altered character and country roads an unsuspected value. Man acquired a new mobility which changed his notions of distance and of time. In

due course the petrol engine also achieved the conquest of the air. At the end of 1903, only a few days after Bramwell's death, the brothers Wright took their first flight in a motor-driven aeroplane. It is the petrol engine that must bear the responsibility—the grave responsibility—of having made it possible for man to fly.

The era of the road motor began with Daimler's experiment of 1887, but a good many years were to pass before it took the dominant position it holds to-day. The horse was already in possession, and did not yield without a struggle. That sensitive animal had a frank dislike of the horseless car. To meet his objections, our legislators—less wise, one hopes, than now—ordained for mechanically-driven vehicles a pace not exceeding four miles an hour, and required each of them to be in charge of three persons, one of whom should carry a red flag in front. Not till 1896 was the Red Flag Act repealed. The sinister emblem has gone, and the horse has nearly gone too. But engineers will not let his memory perish. Thanks to the initiative of James Watt, they treasure his name in one of their most necessary words. The horse may become little more than an instrument of sport or an excuse for betting, but it is safe to say the horse-power will never die.

I have yet to mention another milestone in the history of internal combustion. It was soon recognized that the efficiency of the action depended on the extent to which the combustible mixture in the cylinder was compressed before it was fired; the more compression the greater was the subsequent expansion in the working stroke, and consequently the higher was the efficiency. But a practical limit was set by the danger that the mixture would automatically ignite before the proper time if too much compression were attempted. Users of petrol engines know this danger well; often they try to diminish

it by introducing what are called dopes. It was not in petrol engines, however, but in heavy-oil engines that Rudolph Diesel initiated a change of first-rate importance, about 1895. Instead of compressing a combustible mixture, he compressed the air alone, bringing it to a very high pressure, and thereby making it so hot that when the charge of oil was forcibly injected at the dead-point there was instant ignition. This escaped all risk of pre-ignition and greatly augmented the efficiency of the action, as a thermodynamic consequence of the very high temperature at which the fuel gave up its heat. To force the fuel in, he employed an auxiliary supply of still more highly-compressed air, but this plan is now less common than the simpler one of using a high-pressure pump, which delivers the oil in a spray of exceedingly fine drops. The essential feature of the engine is that the fuel does not enter the cylinder until the air there is highly compressed and the working stroke is about to begin. It is this feature which has made the Diesel engine the most efficient of all known means of obtaining mechanical work from the combustion of fuel. When I say the most efficient, I am using the word in its thermodynamic sense ; other factors obviously enter when you come to consider questions of mechanical simplicity, of suitability for a particular purpose, or of cost.

As a small-power prime-mover in situations where electric supply is not available, such as country houses, farms, or isolated workshops, the convenience of the internal-combustion engine has, in fact, led to its almost universal use in preference to steam.

We have still to speak of how, for larger uses, the steam engine has held its own during this half-century of change. Before doing that, however, it may help us to realize the other side of the matter if we imagine our prophet of 1881 brought back to earth so that he may see for

himself in what measure his expectations have been fulfilled.

He will come, of course, by aeroplane, and on the way the pilot will tell him of the part which the internal-combustion engine played in the war; of submarines, and road-motor transport, and tanks and aircraft. He will be told of Zeppelins and air-raids, of the horrible superiority of attack over defence that characterizes modern war. He will learn how prodigiously man has increased his power to kill his fellows and destroy their works. The old gentleman will be saddened to think that the world owes this to engineers, and especially to the internal-combustion engine. It will grieve him to reflect that the island safety of England has departed, never to return. On the other hand, he will be told of air-mails to India and Australia and the Cape, and it will interest him much to learn that the engine which is bringing him so swiftly and comfortably to earth weighs no more than a couple of pounds per horse-power, and that engines of much the same type, but lightened and tuned to the uttermost for racing, can develop more than a horse-power for every pound of weight. He will hear, perhaps with less enthusiasm, of speed records by air and sea and land, amazing records which are set up only to be broken. ' Brief life is here our portion ' might be said of the records, and also, alas, of many of the record makers and record breakers. As he approaches London our aerial voyager will note the highways thick with motor cars, coaches, and lorries, and will wonder for a moment what has happened to the railway shares he left behind, doubtless selected as a secure investment of the terrestrial fruits of his industry and thrift. For in Bramwell's time there were still people who practised these now exploded virtues, and there were even Chancellors of the Exchequer who encouraged them.

We may imagine that instead of landing at Croydon the pilot brings him over the river and the docks, where he may see big motor-ships like the Nelson liners arriving with their frozen or chilled cargoes. One of his pet bits of engineering was mechanical refrigeration, and he will take particular satisfaction in noticing ships that are not only driven but cooled by internal-combustion engines. And from the docks they will proceed over the City, where at every crossing he will observe the congestion of motor-cars and taxis, and the multitudinous motor-bus—but never a growler, which was the vehicle he used to favour. I well remember his taking me to visit a cold store on the south side of the river ; we were on our way in a growler when the bottom fell out and we found ourselves sitting in the road. He was, as I have hinted, no light weight ; my part in the comedy was only that of the last straw. The cab stopped without injury to life or limb, Bramwell forming an effective automatic brake. His genial dignity suffered no eclipse. His spirits were undamped—and his person too, for luckily the street was dry.

Finally, let us think of the pilot bringing him over Waterloo Place to revive his memories of the beloved club where he used to spend many placid hours. Below him will be the Athenaeum, more than ever a haven of rest for the mature, but now on the outer edge of a vortex which is fed by torrents of one-way traffic from the Haymarket and Trafalgar Square—a veritable inferno of internal combustion—an inferno that would be intolerable were it not tempered from time to time by authoritative outstretchings of the arm of the law. As he watches the maelstrom, and perhaps sees a bishop trying to reach the club, he will thank the fate which has removed him from the present-day terrors of the pedestrian, from compulsions to unseemly agility and temptations to unseemly profanity. Such temptations are, of course, only for lay-

men, but life in Waterloo Place, even for bishops, must sometimes be furious as well as fast.

When all these things have been seen, you must not imagine Bramwell posing as the satisfied prophet who complacently remarks 'I told you so.' He had too judicial a temper for that. He would want to know about other users of power, and would ask many questions. What about our navy, and other navies, and what about the biggest liners and the ocean tramps, and what about the railways and the great factories and the coal-pits with their plant for winding and ventilating, and so forth, and what about the distribution of light and power from central stations—on what kind of prime-movers do these rely? And the answer would be steam, and steam, and yet again steam. He would soon learn that steam still does a great part of the work of the world, and that one need not go to the Science Museum at South Kensington to find specimens of its remains. But if he did go to the Science Museum (and let me say it is a pilgrimage no visitor to London should miss) he would see among the admirably displayed exhibits some remarkable engines. Side by side with the mementoes of Newcomen and Watt, those fascinating heralds of the dawn, he would see engines of a far more recent type, enshrined there in the honour they so well deserve, not as relics of an obsolete past but as precursors of a modern era, the era which was opened to the world by the genius of Charles Parsons. For among the treasures of our national museum of science is Parsons' first steam turbine, which dates from 1884, also the first, or nearly first, turbine to which he fitted a condenser, which dates from 1891, and also a part of his famous little craft, the *Turbinia*, by which in 1897 he demonstrated the applicability of the steam turbine to the propulsion of ships.

These dates, as you will notice, are all subsequent to

Bramwell's prophecy of 1881. Many factors have contributed to prevent that prophecy from being fulfilled, but none have been so potent as Parsons' invention and development of the compound steam turbine. That invention was no isolated event—no mere throwing out of a happy thought. It was the life work of a man who, to an extraordinary degree, combined creative imagination with energy and persistence and practical skill. The recent death of Parsons has deprived this Association of a famous past-President and a generous friend. Section G in particular mourns the loss of the most illustrious of modern engineers. It is fitting that we should dwell for a moment on the greatness of Charles Parsons.

The turbine as we know it now is the product of sustained effort and unquenchable faith. The genius of Parsons was indeed of the kind which includes an infinite capacity for taking pains. He never admitted defeat; difficulties only spurred him to further effort. He loved to attempt tasks which people called impossible. A most exacting judge of his own performance, he was always striving to better what seemed already very good. These qualities made Parsons perhaps the most successful innovator the engineering world has ever known.

It was my privilege to know him from an early stage in his astonishing career. Forty years ago I was commissioned to test and report on his first condensing steam turbine—sent by people who were disposed to be sceptical of the merits of a thing so queer and so untried. The tests were entirely convincing. That was the beginning of a friendship which was broken only by Parsons' death.

At Parsons' own request, I carried out further tests from time to time on occasions when the steam turbine had reached some notable stage in its development. Among these were trials of the *Turbinia*, before she made

her dramatic appearance at the Diamond Jubilee Review in 1897. Her performance established what was then a record of speed for any ship. It prepared the way for a wide adoption of turbine driving in the Navy and the Merchantile Marine. Every opportunity I had, then and later, of seeing Parsons at close quarters, of observing how he would bend his mind to the problem of the moment, increased my admiration of the inventor and my regard for the man. To the last, there was an endearing quality in his self-effacement, in the modesty with which he wore his world-wide fame, which gave him a peculiar charm once the veil of shyness was drawn aside. Now that he is gone, his friends feel that they are sharers in a personal no less than a national loss.

But such a man lives on in his achievements. To Parsons it was granted as to few men to see the fruit of his ideas and his labours. Long before he died the world recognized that he had revolutionized steam engineering. He had taught us how to generate power on a scale and with a concentration never before approached. Nothing, in a sense, could be simpler than his steam windmill with its successive rings of vanes, each in turn taking up a small fraction of the whole energy of the blast. To conceive such a device was one thing, to give it being and action was quite another. That meant many subsidiary inventions and years of toil; it meant the removal of mountains of prejudice. But the triumph is complete. Engineers, all the world over, are whole-heartedly converted. They build their steam windmills on a colossal scale, crowding 50,000 or 100,000, sometimes even 200,000 kilowatts into a single unit, confident in the knowledge that no more trustworthy and economical prime-mover is available for the gigantic stations which play so important a part in modern civilization as centres for the production and distribution of light and of power.

All these stations have come into existence in the fifty years which have passed since Bramwell made his prophecy, and in them it has most conspicuously failed of fulfilment. Review the great power stations of the world, and you find their method of manufacturing electric energy from heat is almost wholly through the medium of steam. In British power stations the returns of the Electricity Commissioners show that oil engines and gas engines together supply only $1\frac{1}{2}$ per cent. of the whole output. Abroad, as well as at home, the steam turbine is dominant. Its dominance is the more appropriate because the turbine was invented in the first instance for the express purpose of driving a dynamo. Parsons realized, in the early eighties, that the generating of electricity gave steam a new job to do, a job that needed high-speed rotation, a job for which reciprocating movement was out of place. So he invented the turbine, in which high-speed rotation was directly produced and was a fundamental feature, and he invented also a high-speed dynamo suitable for it to drive, and he patented them both on the same day in April 1884. The dynamo, he used to say, gave him as much trouble as the turbine. In all the early turbine-driven dynamos it was the armature that was caused to revolve in a gap between the poles of a stationary field-magnet. But later, when a demand came for much greater power and much higher electric potential, the parts were inverted: the field-magnet was caused to revolve, and thereby to generate alternating currents of high potential—often many thousand volts—in a surrounding stator which was made up of highly-insulated coils.

The commanding position of the steam turbine is, of course, mainly due to its high thermodynamic efficiency: in large sizes it gets more work out of coal than can be got in any other way. But apart from that, its avoidance

of reciprocation gives it an advantage which only those who remember early power stations with their piston engines can fully realize. Again, it can readily be built and run in big units, and another merit which appeals strongly to the central-station engineer is its wide range of economical working both above and below its normal load ; this specially fits it for the peaks and variations of demand with which power stations have to cope.

It is in the great power stations equipped with large turbines and coal-fired boilers, using steam of high pressure and high superheat, that we find, beyond any question, the most economical production of power. The very bigness of the units tends towards efficiency, but that is not all. The turbine as a thermodynamic machine has permitted a far closer approach to the ideal cycle of Carnot than was possible in the reciprocating steam engine, which, as Lord Armstrong said, skimmed the cream and threw away the milk. In the turbine the steam expands right down to the lowest vacuum that the condensing water will produce, doing effective work all the way, and thereby saving a most valuable and previously wasted portion of the whole heat-drop. Moreover, with the turbine there is a complete escape from the alternate heating and cooling of metallic surfaces which was a source of much loss in engines of the older type. In still another notable respect the turbine cycle approaches the cycle of Carnot : it allows a method of regenerative feed-heating to be adopted in which some steam is 'bled' at successive stages of the expansion to restore heat to the condensed water on its way back to the boiler. Finally, the steam turbine has immensely widened the range of the thermodynamic cycle by raising the upper limit of temperature through the use of higher pressure and higher superheat. Pressures of 600 to 700 lb. per square inch are now commonplace ; 1,200 lb. is becoming

familiar; 2,000 lb., or even more, is not unknown. Superheating is often carried to 750° or 800° F.—sometimes to 850°, and in rare cases to 900°—and is limited only by the ability of the metallurgist to supply metal that will not 'creep' too seriously under the combined influence of high pressure and high temperature. The more superheating the better, in this respect, that it tends to reduce the wetness of the steam in the late stages of the expansion and so avoid not only a loss of useful energy but also a tendency on the part of the turbine blades near the exhaust end to be pitted as a result of their impact against water particles. Another cure for wetness is to reheat the steam at one or more stages in its expansion; with very high initial pressure this becomes necessary, but opinions differ somewhat as to the conditions that make it worth while to carry out so troublesome an operation. We have no time to discuss moot points or to dwell on details, but enough has perhaps been said to show why the steam turbine in fact achieves an efficiency far greater than was known to the steam engineers of Bramwell's day. A modern turbine can generate one electrical unit with a consumption of barely 1 lb. of cheap coal, which means that it converts into electrical energy fully 30 per cent. of the potential energy of the fuel. It is not surprising that the internal-combustion engine finds little favour in power stations, save as an occasional stand-by to assist in meeting the peak load.¹

Turning now to another field, we find that in railway traction the supremacy of steam is maintained. Higher

¹ Among the merits of steam turbine plant is its comparatively low capital cost. Published figures show that in recently-equipped British power stations the cost, including land, buildings, boilers, turbines, and all electrical machinery is from £14 to £16 per kilowatt of plant installed. For Diesel plant the corresponding capital cost is stated to be from two to four times as great.

pressures and the use of superheating have helped to hold it, and the most progressive locomotive engineers have experiments in progress which may carry practice further along these lines. Much attention has been paid to the Diesel engine as a possible alternative, but so far the number of Diesel locomotives that have found employment in main-line working is a negligible proportion of the whole. If the steam locomotive is to disappear, there is no indication that its place will be taken by an internal-combustion rival. What is much more likely is that it will in time be driven out—wholly or in part—by electric traction, as Lord Weir's Committee has recently suggested for the British railways. But electrification will mean that the prime-mover is still steam, though acting at a central station—except, of course, in countries which have available reserves of hydraulic power.

Such a country is Switzerland, and there the transformation from the steam locomotive to electric traction is already almost complete. The playground of Europe has lost little or nothing of its charm through becoming dotted with hydraulic power houses. Already its exports to less favoured neighbours include many million units of electric energy which it delivers through the graceful catenaries that girdle its mountains and span its valleys. The shrewd inhabitants doubtless demand a remunerative price for exported electricity, just as they quite properly do for the other amenities of their delightful land. A time may come when subterranean stores of coal and oil run low, but so long as the sun shines and the rain falls mankind will be able to continue its struggle for existence, though it may suffer a change in the centre of gravity of its industrial life. Industry will learn, like the Psalmist, to look to the hills from whence cometh its help, and Geneva will be more than ever the natural

rallying point of a community of nations, physically linked by a comprehensive 'grid' on which they depend for whatever modicum of light and power they are still permitted to enjoy.

For road motors, the internal-combustion engine is, of course, supreme; it has created as well as supplied a vast demand. Mr. Ricardo, writing in 1928,¹ said that the output of high-speed internal-combustion engines exceeded by more than ten times the total horse-power of all power stations, ships, and railways. A statement at the World Power Conference, held in Berlin in 1930, gave the number of motor-cars on the world's roads as thirty millions, with an output of at least 600,000,000 horse-power. I have not attempted to check these estimates; I do not suspect them of exaggeration; I am only thankful that many of the engines referred to spend a great part of their time in garages and parking places and are not in a state of continuous activity. They have come into existence to meet a new need; they do not, for the most part, enter into competition with the older uses of steam on land, except by diverting traffic from the railways to the roads. In their own special field—the roads and the air—they have an unchallenged monopoly. And, indeed, they well deserve it. We ought, I think, to pay tribute to the constructive talent that has made these engines the convenient and reliable prime-movers they have in fact become. Let me quote in this connection some very just remarks by Mr. Ricardo, who has himself done not a little towards securing the admirable results he here describes:

'With the advent of this class of engine there has been a marked change of attitude as regards both the manu-

¹ H. R. Ricardo on 'Light High-Speed Internal-Combustion Engines,' Institution of Civil Engineers, Engineering Conference, 1928.

facture and the handling of prime-movers. In the past, a prime-mover was regarded as a delicate piece of mechanism, luxuriously housed, and served by skilled engineers trained to anticipate all its needs and to minister to its ailments. To-day, the high-speed internal-combustion engine receives no such special care; more than half the engines produced are tended by people who have no idea of how they work, and who consider that their obligations are fulfilled so long as they keep one compartment reasonably full of fuel and another of lubricating oil; it is for such usage that the engine must be designed. A typical example of the modern attitude towards the high-speed engine is to be found in the case of the motor-bus. The modern bus engine is capable of developing 70 to 80 horse-power and of running at piston-speeds exceeding 2,000 feet per minute; it is placed in the hands of a driver who knows nothing about engineering generally, or of his engine in particular. Such an engine runs 16 hours daily under very arduous conditions and, in the ordinary course of events, it continues so to do for six months before it receives any skilled attention. It is obvious that to withstand such usage an engine must be reliable.'

One may note in passing the remarkably successful efforts which have lately been made towards reducing the weight of high-speed engines which will burn heavy oil instead of petrol, with the consequent advantage (over petrol) of greater efficiency, less weight of fuel, greater safety, and smaller running cost. Light engines of this type open up new possibilities in the air, as well as on the road and on the sea.

This brings me to the last field which must be surveyed in our brief review—the field of ocean navigation. And here we find a situation which is puzzling, unsettled, and difficult to analyse. For in the selection of prime-movers for ocean-going ships there are sharp differences

of opinion and of practice ; there is no sense of finality ; there is even—so it seems to me—a good deal of fashion and caprice, and of the probability of change which one associates with such moods of the mind. I do not suggest that superintending engineers are ever capricious or unreasoning ; indeed, if the matter were really left to them I believe it would soon settle itself ; but even a layman in marine matters knows that a shipping company's policy in questions of propulsion is sometimes governed by other factors than the considered judgment of the superintending engineer.

In our own navy and foreign navies there is a practical monopoly on the part of steam except, of course, in submarines. The advent of the steam turbine, of oil fuel, of gearing between turbine and propeller shafts, of water-tube boilers, of higher pressure, and of super-heating—all these progressive improvements have only consolidated the position. Foreign navies have followed the British lead, and, for surface vessels, the only departure from that rule is to be found in a new German cruiser, which is still something of a mystery ship. Except for this rare and as yet unfledged bird, naval usage sticks to steam.

But the mercantile marine is in a state of flux. Before the war there were almost no motor-driven ships. Vigorous efforts had been made to promote the use of gas engines with producer gas made on board as it was required, but these achieved no permanent success. The *Selandia*, which dates from 1912, was the first conspicuous example of a large ship driven by Diesel engines. Her economy of fuel at once commanded attention. She was naturally hailed with delight by the powerful oil interests whose position, already strong in the mercantile marine through the extended use of oil as a furnace fuel under boilers, would become impregnable if the Diesel engine

were generally adopted. In some important quarters the Diesel engine became the vogue. During the post-war years of marine reconstruction the number of oil-driven motor-ships rapidly increased, and it is still increasing. In 1930, according to Lloyd's Register, the gross tonnage of the world's shipping was in round figures $69\frac{1}{2}$ million tons, of which $1\frac{1}{2}$ million were survivors from the ancient régime of sails. Of the 68 million tons that were mechanically propelled 60 million tons were steam-ships and 8 million tons were motor-ships. The motor tonnage had increased nearly fourfold in the preceding three years. Of merchant vessels launched during the year 1930, considerably more than half the tonnage was motor-driven; and even in Great Britain the motor tonnage launched in that year was nearly 52 per cent. of the whole tonnage launched. For the moment the motor-ship is in the ascendant. At this rate, a superficial observer might fancy that steam was in process of being driven off the high seas. But if that were his conclusion I think he would be quite wrong.

If you look at the list of shipping in detail you will notice several things. One is that none of the greatest and fastest ships are motor-driven—neither the *Leviathan*, which at present heads the list, nor any of the other leviathans of the deep, with their 40,000 or 50,000 tons or more, and their speeds ranging from 20 to 28 knots. And this is true not only of the older ships but also of the newest, such as the *Europa* and the *Bremen* and the *Empress of Britain*, and the giant Cunarder which is now on the stocks and is expected to eclipse them all. For such vessels, motors do not give the concentration of power that is needed, whereas turbines do give it, and give it easily. The present fashion, if one may call it so, is to put motors into ships of moderate size and power. Reciprocating steam engines are still built for compara-

tively small and slow ships. The ocean tramp is perhaps regrettably conservative in the manner in which she uses steam, but for ships of larger power the advantage of the turbine is too conspicuous to be ignored.

Of motor-driven ships many are tankers, a type that has been called into existence by the world's demand for transport of oil in bulk, both for internal-combustion engines and for burning under boilers. Of tonnage launched during 1930 the tankers constitute more than 30 per cent. of the whole output. About seven-eighths of these are motor-driven ; they carry oil and, naturally enough, consume it. Motor-driven tankers account for half the world aggregate of motor tonnage launched in 1930.

It is when we turn to vessels of intermediate types, to cargo liners and passenger liners which, though not of the largest class, are important ships, often catering for the luxurious traveller, that we find the liveliest contest between the steam turbine and the Diesel motor. And here one notes the curiously potent influence of nationality and of what may be called the accident of ownership. Some nations, such as Denmark, Norway, and Sweden, conspicuously favour motors. Others, such as America, no less conspicuously favour steam. One feels that both cannot be right. Nor can British practice, which is much divided, be right either. The choice would sometimes seem to depend more upon the taste and fancy of some dominating personality than upon a careful weighing of arguments such as appeal to engineers. One finds some shipowning companies going strongly for Diesel engines and other companies going no less strongly for steam. A notable example in the steam group is the Canadian Pacific Company, whose superintending engineer, Mr. J. Johnson, has communicated to the Naval Architects a very full statement of the grounds

which have governed that company's engine policy.¹ His paper deserves careful study; I have not been able to find any equally detailed and convincing statement on the other side.

A point which will be plain to any reader of Mr. Johnson's paper is this, that to make a fair comparison of performance you must take both types at their certainly attainable best. You must not compare modern Diesel engines with steam engines of an antiquated type, but with turbines working under conditions that have been demonstrated to be practicable at sea, where high pressure and high temperature, with water-tube boilers, pure distilled water, no oil in the steam, and sound condenser tubes maintain an efficiency comparable with that which can be reached in the internal-combustion engine. It is right to recognize that the competition of the turbine with the Diesel engine has helped to develop on board ship an improvement in the efficiency of steam for which the way was already prepared by the experience of central stations ashore. Largely through the preaching and example of Parsons, we have learnt that the future of steam in marine propulsion depends on high pressure and high superheat. The experience of Mr. Johnson rubs this in.

When we attempt to appraise the merits of the rivals and to estimate their chances in the more distant future, we see that from the thermodynamic point of view the Diesel engine still has a small advantage. On the other hand, its oil is more costly than fuel oil for boilers, it must have lubricating oil, too, and the first cost of the engine is substantially greater than that of steam plant. In respect of weight and of space occupied there is not

¹ 'The Propulsion of Ships by Modern Steam Machinery.' *Trans. Inst. Nav. Arch.*, 1929, vol. 71, p. 39. [See also a further paper by Mr. Johnson on 'Fuel for Merchant Ships,' vol. 74, 1932.]

much to choose ; when account is taken of all accessories there is, perhaps, a slight advantage on the side of steam. As to durability, I cannot speak ; so far as I know, there is still a dearth of published facts about the cost of upkeep with Diesel engines. *Prima facie*, the great number of reciprocating parts is a serious drawback. There must be a great number because the safe limit of cylinder size is soon reached, and it is only by having many cylinders that any large aggregate of power is developed. In a recent Diesel-engined liner of the luxurious type, a ship of some 17,000 or 18,000 tons, 12 Diesel cylinders operate on each of four shafts, making 48 in all, to produce a speed of 18 to 20 knots. Besides these 48 main cylinders, there are 24 more which serve purposes that are auxiliary but essential to the working of the main engines. Consider the number of working joints, of valves, of valve-rods and tappets, besides pistons and connecting-rods, which this involves. Does such an accumulation of reciprocating pieces with their hammer-blow accelerations mark a real engineering advance as compared with the cosy hum of a turbine engine room, and has it come to stay ? Frankly, I think not.

As a last technical point I would say a few words about fuel for marine engines. Can anything be done to re-establish the ancient connection of the merchant service with the British coal-fields ? Remember that here and in most other places, the cost of coal is substantially less than that of oil, for the same quantity of heat. Where oil scores is in its greater convenience of handling. Much has been said and written about restoring prosperity to the miners by converting coal into oil. As a chemical operation, it is quite possible to make oil from coal ; as a commercial proposition it is impracticable, so long as nature continues to supply oil directly from

the bountiful stores on which man now draws with careless and prodigal ease. Ships that burn oil must have it come to them from sources outside Great Britain. Well, then, can we expect ships to return to the use of coal as fuel? For some classes of ships I think we may, though not all classes. Neither in the Navy nor in what one may call the upper division of the Mercantile Marine—the luxurious express liners which carry fastidious passengers and must keep to a time-table that means quick fuelling—can one expect a reversion to coal so long as oil fuel can be got at anything like its present price. But with cargo liners and big cargo boats, the case is different. They do offer a possible field for the use of coal, a field where I believe its use would be economically sound as well as of great national advantage. In the running of such ships, the incidental conveniences of oil fuel count for less. The cost of fuel is a relatively big factor, and there is a clear advantage in being able to burn either coal or oil at option, according to the local cheapness of supply. There the geared turbine with coal fuel can more than hold its own provided the steam plant embodies the conditions that make for high efficiency, conditions which are now known to be attainable in marine practice. I think those engineers are right who contend that for such ships a highly economic mode of working would be to use pulverized coal for steam-raising in a small number of large boilers of the water-tube type, with a pressure of, say, 500 lb. and a temperature of 750° F., each boiler having its own pulverizing mill and being fitted also for burning oil as an alternative fuel. In such a scheme there would be no untried elements, but the combination of the elements would be experimental, and a conclusive demonstration of its advantages can be obtained only by testing it out on a large scale in sea-going ships, trading on more than one route. An

experiment of this kind is well worth the making. It is a matter of national moment to help a threatened industry by finding an increased use for coal ; that aspect of it should not be overlooked by those who are willing to subsidize industrial research. Such expenditure would be a casting of bread upon the waters with a good prospect of its ultimate return.

And now we take leave of our prophet of 1881. We may fancy him borne aloft in a fiery chariot whose fires are unseen only because they burn within the cylinders. If we were to catch from him the mantle of prophecy, we should wear it ruefully ; we should all be Cassandras or Jeremiahs, obsessed with the cheerlessness of the industrial outlook, and finding no escape from the conviction that the easy supremacy of Britain, as Bramwell knew it, can never be recalled. But my last word must not be an unqualified Ichabod. The engineers of to-day have as much courage and enterprise as their fathers, and they have a vastly better understanding of the scientific principles on which, as on a smooth highway, the advance of engineering must steadily proceed. Moreover, to recognize evils, and the causes of evils, may be the first step towards their cure. The world has learnt, through a sharp lesson, that the gifts of the engineer are good gifts only if they are wisely used ; that the new powers he has evoked have brought new dangers against which mankind must resolutely guard if it is to save its soul alive. Individuals and nations now command forces of destruction such as more primitive communities never knew, and were happier not to know. And apart from clamant and appalling abuses of gifts which ought to be beneficent, we have become aware of a more subtle and perhaps graver social menace. We see the mechanized arts of production overreaching themselves, supplying commodities in a volume which cannot be absorbed, and

with a facility that tends to deprive man of his richest blessing to body and spirit—the necessity of toil.

But these thoughts take us too far afield. They point to problems now conspicuously urgent, which, for the salvation of society, the engineer, the economist, and the moralist must jointly set themselves to solve.

1931

V

MAGNETISM

BEING THE 'JAMES FORREST' LECTURE FOR 1899 AT
THE INSTITUTION OF CIVIL ENGINEERS

WHEN the Council of the Institution honoured me with an invitation to deliver the 'James Forrest' lecture they suggested 'Magnetism' as the subject. I felt at the time that it was like prescribing an ox roasted whole for an invalid's lunch. How could one treat a theme so vast with any hope of making it palatable? But, having nothing better to propose, I acquiesced, and I now find myself confronted by the uncomfortable task of presenting a dish that may give you indigestion.

Whatever be his subject, the duty of the 'James Forrest' lecturer is to treat it as an illustration of the bearing of science upon practice. He has to show how the visions of the philosopher become translated into the matter of fact of the engineer; how observations and theories which at first awaken only intellectual interest are in time found to have application to the use and convenience of man. He has to show that if necessity is the mother of invention, science is often its foster-mother. And there is another side to the matter, for if the lecturer discharges his duty aright he will show how practice pays back its debt to science; how the progress of invention stimulates discovery; how the laboratory owes as much to the workshop as the workshop owes to the laboratory.

Time was when it might have been appropriate in addressing an audience of engineers to plead for the better recognition of science as the handmaid or mistress of practice. But there is no need to do that now. The service which each does to the other is recognized ; the beneficent reaction between them has, in late years especially, been too fruitful to escape notice. Whatever barrier used to be apparent has broken down. Day by day more points of contact are found, more grounds of sympathy, more opportunity for co-operation. To one who, like your lecturer, has his affections divided between physics and engineering it is pleasant to note that in language, in mental habit, in appreciation of experiment and in other ways, engineers become more akin to physicists, and physicists become more able to observe nature from the standpoint of the engineer. There will always, we need not doubt, remain two schools, one serving abstract truth, the other with little interest save for what promises application. But between those extremes you find men of more catholic spirit, whose zest for scientific discovery is none the less keen because they have an eye to the uses to which some of it may be put. The achievements in the world of practice of a Kelvin or a Hopkinson are as remarkable as their discoveries in pure science. I mention great names, but there are many lesser men who follow in their footsteps.

Certainly it would be difficult to find a subject better fitted than magnetism to illustrate the harmony of practice and science. The applications of magnetism are older than the science—so old that they are lost in the mists of a remote past. If we cast our eyes far enough back they light on the traditional and shadowy figure of the Chinese imperial navigator Hoang Ti, who, some twenty-four centuries before the Christian era, is said to have piloted his fleet of conquering junks by the aid

of a floating fragment of loadstone. The loadstone, a natural magnet composed of the magnetic oxide of iron, is found in the magnetized state at many places on the earth's surface, and notably at Magnesia, in Asia Minor, which led Euripides to call it the magnetan stone. Though the writings of Plato and Pliny and Lucretius contain many references to the properties of the loadstone and many curious legends concerning it, it is remarkable that neither the Greeks nor the Romans were aware of its use in navigation. We are told in the Book of Acts that St. Paul, after staying three days at Syracuse, 'fetched a compass' and came to Rhegium, but any student of the Institution will tell you it was not a mariner's compass that he fetched.

Though the uses of magnetism were unknown in classical times, its abuses appear to have flourished then, as they do still. The loadstone was reputed to free women from witchcraft and to put demons to flight. A magnet pickled with the salt of the sucking-fish could draw water from the bottom of the deepest well. Iron rings magnetized by rubbing against a loadstone were a remedy for the gout, and the priests of Samothrace, five centuries before the Christian era, are said to have made a tidy revenue by selling those ancient prototypes of the modern magnetic belt. The mysteries of magnetism have in all ages formed a happy hunting-ground for lovers of the occult. Quackery and superstition have found it a name to conjure with. The fact that a thing is unintelligible has been held sufficient reason for dubbing it magnetic. It is no part of my business to speak of 'Animal Magnetism,' for whatever elements of fact there are in the reported phenomena which go by that name, we may rest assured that with magnetism they have nothing whatever to do. It is a striking fact that among our bodily senses we have nothing to help us to

a perception of magnetic activity. The sense of sight may indeed be called a magnetic sense when regard is had to the principle that light is made up of electro-magnetic waves, but you may put your hand or your head between the poles of the most powerful magnet and be unable to tell whether the magnet is or is not in action. We have no direct perception of the magnetic field, and there is no such thing as animal magnetism in any legitimate use of the term.

According to one story it was Marco Polo, the Venetian, who brought the mariner's compass from China to Europe in the thirteenth century. Anyhow its use was known then, though the attractive influence was wrongly localized, being ascribed to one of the stars in the tail of the Great Bear. The Provençal poet Guiot, in a MS. of the thirteenth century, tells at length, as if it were rather a new thing then, how a steel needle may be magnetized by touching it with a loadstone, and how when put through a piece of straw and set floating, it always points to the north :

'Puis se torne la point toute
Contre l'estoile sans doute.'

A letter of Peter Peregrinus written in 1269 contains a remarkably good account of the polar quality of the magnet and of its use in finding the north. By the time of Columbus the compass, with its divided card, was apparently a common appliance in navigation. It was during his first voyage to America in 1492 that Columbus discovered the variable deviation of the needle from the true north. The fact that the balanced needle does not lie horizontally, but dips, was discovered by a London instrument maker called Norman in 1576.

We may take it, then, that applications of magnetism were known certainly six hundred, perhaps five thousand

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A letter of Peter Peregrinus written in 1269 contains a remarkably good account of the polar quality of the magnet and of its use in finding the north. By the time of Columbus the compass, with its divided card, was apparently a common appliance in navigation. It was during his first voyage to America in 1492 that Columbus discovered the variable deviation of the needle from the true north. The fact that the balanced needle does not lie horizontally, but dips, was discovered by a London instrument maker called Norman in 1576.

We may take it, then, that applications of magnetism were known certainly six hundred, perhaps five thousand

years ago. But the science of magnetism is just three hundred years old ; it dates from the publication, in the year 1600, of the treatise 'De Magnete' by William Gilbert. In that remarkable book the speculations of the schoolmen and the 'old wives' tales' which had gathered about the subject were brushed aside, and the foundations of magnetic philosophy were laid on the safe ground of experiment. Gilbert showed, by means of a model globe cut out of loadstone, that the behaviour of the compass needle was to be explained by regarding the earth itself as a great magnet, surrounded consequently by an 'orbis virtutis'—a sphere of influence, or, as we should now call it, a magnetic field. Time would fail me to tell you of the many acute observations described by Gilbert, which entitle him to high rank among the founders of experimental science. Galileo, his even greater contemporary, said : 'I extremely admire and envy the author of "De Magnete" ;' and Dryden wrote this panegyric :

' Gilbert shall live till loadstones cease to draw,
Or British fleets the boundless oceans awe.'

This last line suggests the remark that if Dryden could see the naval estimates for the present year of grace—and of aspiration after general disarmament¹—he would surely have no misgivings as to the permanence of Gilbert's fame.

It would be easy to occupy the whole of the lecture in telling of the subsequent developments of that first application of magnetism, the mariner's compass ; of the new problems which presented themselves when magnetizable metals—iron and steel—took the place of timber in the construction of ships ; of the analysis by Archibald Smith of the various disturbing influences which the

¹ This was written in 1899.

magnetism of the ship exerts ; and of the inventions by which Lord Kelvin brought the compass to its present state of perfection and enabled correcting devices to be applied by which the effects of the ship's magnetism are neutralized. In Lord Kelvin's compass we have a striking instance of the results that are achieved when profound scientific insight works hand in hand with rare practical instinct and inventive skill. I wish I could dwell on so attractive a theme, but I must hasten to speak of other developments and applications of the science of magnetism.

The pivoted needle of the compass turns so that it may place itself in the direction of the lines of force of the magnetic field ; so long as no local disturbing cause acts, the field is that due to the magnetism of the earth. But Oersted discovered, in 1820, that if a wire conveying an electric current were brought near, the needle became deflected, because (as we now know) the current produces a magnetic field on its own account, whose lines of force encircle the conducting wire. Eleven years later Schweiger showed how this effect could be intensified by winding the conductor into a coil, in the middle of which the pivoted needle was set, and thereby invented the galvanometer. The laws of the phenomenon were investigated by Ampère and by Weber, and thus the way was paved for the introduction in 1837 of the needle telegraph by Cooke and Wheatstone. What that lusty infant, the telegraph, has grown to in the intervening sixty years you do not need to be told. Our distant colonies are bound to the mother country not simply by links of loyalty and mutual affection, but by material bonds of copper which have no small part to play in the building and sustaining of Empire.

The suspended needle, by which Cooke and Wheatstone gave practical application to the discovery of Oersted,

did not long remain the sole, or even the chief, instrument in telegraphy. It was almost at once supplemented, and soon to a great extent displaced, by the family of instruments which depend on the attraction which an electromagnet exerts on a movable armature, instruments of which the telegraph of Morse was the first to take working shape. But Oersted's discovery met with a second great application at the hands of Lord Kelvin in 1858, when the problem of signalling at a remunerative speed through long ocean cables was solved by his invention of the mirror galvanometer, which at the same time supplied physicists with an invaluable new instrument of research. Later his siphon-recorder allowed the delicate fluctuations of current, which constitute the signals in such a cable, to be registered as well as read. In the galvanometer the coil is held fixed and the magnet moves. In the recorder the force between the two is still the operative force, but it is the coil that moves while the magnet is held fixed.

Morse's telegraph was a practical fruit of the discoveries of Ampère and Sturgeon. Ampère had shown that pieces of steel might be permanently magnetized by placing them inside a coil of wire, within which a magnetic field was established by passing an electric current through the wire. Sturgeon, in 1825, substituted a soft-iron core for the steel, and pointed out that it acquired strong magnetism so long as the current flowed through the surrounding coil, but lost its magnetism when the current ceased to flow. On establishing the current the iron core underwent, as he says, a 'transition from a state of total inactivity to vigorous polarity', and exhibited 'an intensity of action far surpassing that of any known permanent magnet'. Joseph Henry improved the winding of Sturgeon's electromagnet and used it, by means of a movable armature, to sound a bell at a distance from the operator. From this the step was easy to the record-

ing telegraph of Morse. Simplified into the 'sounder', this remains one of the most ordinary appliances of the telegraphist, and the principle it embodies finds application in the Wheatstone automatic receiver, in the type-printing telegraph familiar to those who study the 'tape', and in a host of other forms.

Faraday's discovery, made in 1831, that a current of electricity is induced in a conducting circuit when it is moved in a magnetic field, in such a way as to vary the number of lines of force which it encloses, led to the invention of the magneto-electric machine, where the movement of the armature of a permanent magnet is used to induce currents in a coil. This has found many uses. It was applied in telegraphy by Wheatstone as the transmitting device in his step-by-step or A B C apparatus. Substantially the same principle formed the basis of the original telephone of Graham Bell. There the movement of an iron disk by the speaker's voice induced corresponding currents in a coil, through the agency of a magnet to which the disk acted as armature, the movements of the disk having the effect of varying the magnetic field within the coil. These currents passed to the distant end and gave rise to corresponding movements on the part of a second disk, in an instrument which was an exact counterpart of the first. I was old enough in 1876 to appreciate the charm of this weird and exquisite invention, and looking back now, it seems, as it seemed then, alike in its novelty, in the vastness of its consequences and in the simplicity of its means, to be the most marvellous of all the wonder-compelling applications of magnetism. The magneto-electric method of generating telephone currents, introduced by Bell, gave place, in the hands of Edison and Hughes, to other and better means, but the receiving portion of the apparatus retains substantially the form which he gave it. The varying

attraction for its armature of a magnet which is strengthened and weakened by the transmitted currents is still used to cause the vibrations of the disk which convert those currents into speech. The latest advance in telegraphy, the achievement of Marconi in communicating between France and England without an intervening wire, is as much as any other a direct fruit of magnetic research. When an electric current comes into existence the magnetic field which it induces around it does not spread through space instantly but with a limited velocity. A current undergoing rapid oscillations, such as a discharge surging back and forth between two plates, consequently sets up magnetic waves of corresponding frequency which travel out into space with a velocity that is, in fact, the velocity of light. These waves of magnetic induction were pictured by the mathematical imagination of Maxwell; and they were demonstrated by the experiments of Hertz, who showed us how to detect their presence at points which might be fairly distant from the source. The researches of Branly and Lodge gave far more delicate means than Hertz had used to discern the arrival of these magnetic waves; and Lodge, who has devoted much attention to the subject, has also been successful in developing appliances for sending and receiving signals over long distances by comparatively long-period waves of magnetic induction, using closed circuits at each end of the system, tuned into electric synchronism, so that the magnetic oscillations sent out by one of them are detected by aid of electromagnetic resonance in the other. The most striking success which the nineteenth century has witnessed in this application of magnetism is Marconi's use of short-period Hertzian waves to signal across the Channel from the South Foreland to Boulogne. Mr. Marconi is to be warmly congratulated on accomplishing this remarkable feat, which has arrested the

attention alike of the public and of specialists, and opened all eyes to the practical capabilities of this new telegraphy.

It is interesting to note in passing, though it is scarcely relevant to my subject, that telegraphy by waves of magnetic induction is the oldest telegraphy of all. Maxwell's conclusion that the waves which constitute light are nothing else than very quick-period waves of magnetic induction was abundantly verified by the work of Hertz, who succeeded in submitting artificial magnetic waves to the reflection, refraction, and polarization which we are familiar with in the case of light. Hence the heliograph, the venerable semaphore, and all the visual signals that have been used from the day when Eve first smiled to Adam, are examples of magnetic wave telegraphy, though I cannot claim them as fruits of magnetic research. In the use of that most delicate of electromagnetic receivers, the eye, we must admit that practice came before science.

Faraday's great discovery of the induction of electric currents by moving a conductor in a magnetic field of force led, as we have seen, to the magneto-electric machine. A permanent steel magnet served to produce the field, and the coils in which current was induced were generally wound upon an armature, which revolved between the poles. The early machines of Clarke and Pixii were improved upon by Wilde, who used a second machine to generate a current which was employed in magnetizing the field-magnets of the first. From this to the invention of the dynamo was a step so natural that we need not wonder it was taken independently, and almost simultaneously, about the beginning of 1867, by no fewer than three inventors, Wheatstone, Werner Siemens, and Alfred Varley. Up to that time the magneto-electric machine, when considered from the engineer's standpoint as an engine for producing electrical energy by the expenditure

of mechanical work, had been little more than a toy. But the abolition of permanent magnets, and the substitution of soft-iron cores excited by the current generated in the machine itself, constituted a revolution ; and the dynamo became a means of applying power to generate electric currents on a grand scale. I do not mean that the change came all at once ; it is a far cry from the “ A ” Gramme’ of twenty years ago to the big dynamos of to-day. But the introduction of the self-exciting field-magnet was the decisive step which made the mechanical production of electric currents a part of engineering—a large part, indeed, as it has since become.

The dynamo machine underwent a course of improvement which was, in part, a consequence of its design being seriously taken up by mechanical engineers, but in great part also the result of magnetic research. To no man did it owe more than to one who was lately taken from us in the fullness of his powers and in circumstances of peculiar sadness. John Hopkinson’s contributions to the development of the modern dynamo were many, but I would specially refer here to his theory of the magnetic circuit. Though the idea of a magnetic circuit had been more or less vaguely present, mainly by analogy, in the minds of other thinkers, it was for the first time explicitly formulated in a way to command assent in a Paper by the brothers John and Edward Hopkinson, and was further applied by them with remarkable effect to problems of dynamo design. A right appreciation of the principle of the magnetic circuit has been one powerful factor in the evolution of the modern dynamo. Another has been the advance which has taken place, through experimental research, in our knowledge of the magnetic qualities of iron. I shall endeavour, before we have done, to pass in rapid review some of the principal facts in magnetism with which the dynamo builder is concerned.

Imagine a conductor wound into a coil which carries an electric current. Each of the lines of force, or, as we will rather call them for the present purpose, lines of magnetic induction due to the current, passes through the interior of the coil and returns into itself through external space. The path taken by these lines constitutes the magnetic circuit ; it is interlocked with the circuit of the conductor, and in this instance it fills all space, for the lines returning outside the coil are spread without limit. Imagine next that the coil is a long helix, and that it is bent round to form an endless ring. The lines of induction are now confined to the interior of the ring ; they still form a closed circuit interlocked with the circuit of the conductor, but they now close themselves without spreading into outside space. If we strengthen the current in the coil, we strengthen the induction in the magnetic circuit. If we fill the space within the coil full of one substance or another, we find in general very trifling variations in the induction within. But if one of the three metals, iron, nickel, or cobalt, be placed as a core within the coil, especially if the one chosen be soft iron, we find an enormous difference. The induction within the coil is then many times greater—it may even be thousands of times greater—than it was before the iron was put in. This familiar fact is expressed by saying that iron and, in a lesser degree, nickel and cobalt possess exceptional permeability to magnetic induction.

A core of iron, however strongly magnetized, would be of no service in a dynamo unless we imagine a gap to be cut in it, where the conductor, whose movement across the lines of induction is to produce current, can be placed. The practical function of the field-magnets is simply to produce a strong induction in the narrow gap where the armature-coils revolve. The business of the fixed coils, to which the magnetization is due, is to establish a mixed

magnetic circuit, forcing the magnetic induction not only through the iron, but across the much less permeable gap. Hopkinson's discussion of the magnetic circuit showed how it might be arranged in the way most favourable to efficiency, and how, knowing the dimensions of the system and the magnetic quality of the iron, we could predicate what amount of magnetic induction would be set up in the gap by a given current in the field-magnet's coils, and hence predetermine the behaviour of the machine.

No sooner was the dynamo introduced than it was discovered that its function could be reversed. Given a supply of electric current, the dynamo, acting as a motor, would serve to convert the energy of the current into mechanical work. This opened up an immense additional field for the industrial uses of magnetism. I need not take up time by referring to matters of everyday observation. No one does not know how the dynamo, acting both as generator and as motor, has given us a new branch of engineering of so vigorous growth that it almost threatens to eclipse the parent stem. It has given us electric lighting and the electric distribution of power. It has taught us to harness Niagara, where, in a recent visit, I was glad to see that the engineers have still left some water, and other waterfalls, where I am sorry to think they have left none. It has created new metallurgical processes and new chemical manufactures with the aid of the electric furnace and the electrolytic vat. It has given us electric railways and tramways, or, rather, it has given them to our neighbours on the Continent and our friends over the sea, for at present you will find more electric traction in a single American or Canadian city than in the whole of Great Britain.

Faraday's further discovery that the induction of magnetism in an iron core by setting up a current in a

surrounding coil would induce a current in a second coil wound upon the same core was the parent of the induction-coil and the transformer. Alternating currents in the primary circuit produce reversals of magnetism in the core, and thereby induce corresponding alternating currents in the secondary circuit, the ratio of electric pressure between the two depending on the number of turns in the winding of the two coils. It is to the induction-coil that we owe the high-pressure currents required for Hertzian telegraphy and for the Röntgen rays. The transformer—an induction-coil with a core closed upon itself to form a complete magnetic circuit in iron—gives the engineer a means of economically conveying electric energy over long distances, by first raising it to a pressure which may be transmitted with but little loss in a long conducting wire of moderate size, and then lowering it to a pressure at which it may be utilized without inconvenience or danger. The principle found its earliest engineering embodiment in the crudely designed 'secondary generators' of Gaulard and Gibbs. Here we have another notable application of magnetism, and it may be added that it is by applying magnetic theory and magnetic experiment that the conditions are practically arrived at which allow the conversion of electricity by the transformer to be performed efficiently. Here, too, a study of the magnetic qualities of iron is all-important to the electrical engineer.

A few incidental applications of magnetism to engineering purposes remain to be mentioned. The attraction across a surface of division between two parts of a magnetic circuit, originally investigated by Joule in 1838, is made use of in the workshop in a variety of ways. Magnetic crane-hooks are employed to lay hold of and lift heavy plates. Drills and other tools are attached by magnetic attraction to the piece on which

they are to work. Magnetic clutches serve to connect and disconnect lines of shafting. Magnetic brakes have been applied to the wheels of vehicles. In all these cases the force which is taken advantage of is due to magnetization ; it comes and goes with the making and breaking of the magnetizing current, and it may readily be made to amount to nearly 200 lb. per square inch.

Thermo-magnetic engines have been devised to perform directly the conversion of heat into work. A piece of iron heated to bright redness (say 780° C.) loses nearly all its capacity for magnetic induction and ceases to be attracted by a magnet. It may therefore be withdrawn from the neighbourhood of a magnet pole without expenditure of work ; but once the iron is cooled the magnet resumes its attraction. Hence by heating the iron when it is in a strong field, then removing it while hot to a place where the field is weaker, then cooling it till the magnetic action reasserts itself and then allowing it to return, we take it through a cycle of positions in which mechanical work is done by it, work which may be applied to a useful purpose by appropriate means. The energy to do the work comes from heat, more heat being absorbed in the heating of the iron than is given out in the cooling. But though it is easy to make a working model which will illustrate the principle of this action, the task of making an engine which will carry it out efficiently on a practical scale has not been accomplished, nor is it in the least likely of accomplishment.

Yet another application of magnetism, and one with a more promising future, is the use of the magnetic field in separating magnetic from non-magnetic substances. A familiar instance is the workshop process of separating iron filings and turnings from brass. Edison has lately turned this idea to practical account by employing magnets in the concentration of iron ore. One of the

most widely diffused ores of iron is the magnetic oxide—the material of the loadstone—which is susceptible to magnetic induction, and is therefore attracted by the magnet. In most cases it is so much intermixed with foreign matter that to smelt the mixture would not be remunerative. Edison's process renders it possible to work such low-grade ore economically. He first grinds it, and for the operation of grinding he has devised machinery remarkable for its boldness in conception and its ingenuity in detail. He then causes the ground mass to fall in a stream before the face of a magnet which deflects the particles that are capable of attraction; so that, while the earthy matter continues to fall vertically, the concentrated ore falls to one side and is separated out. In practice the crushing and magnetic separation proceed in a long series of stages. Through this process of concentrating low-grade iron ore by magnetic winnowing, as one may call it, Edison hopes, and apparently not without reason, to unlock vast natural stores of iron which have hitherto been unavailable, and he has shown the courage of his convictions by spending great sums on the plant by which the process is now being tested on a commercial scale. An English syndicate has taken up the matter, and the prospector is already at work searching in the Scottish highlands for beds of mixed magnetic ore. In this search he is guided in the first place by the magnetic survey of Rücker and Thorpe, expecting, *prima facie*, to find deposits of ore where they have detected local perturbations of the terrestrial magnetic field. Here we have an example of what occurs over and over again in the history of scientific discovery. A utilitarian application unexpectedly follows a piece of scientific research which at the time it was made seemed to have none but the most abstract interest. In the evolution of engineering few things are more con-

spicuous than the ultimate usefulness of 'useless' knowledge.

The electrical engineer requires special iron to derive the best results in his dynamos and transformers, and the supply of it has become an important industry. It is important that some foreign substances should be carefully excluded, and small quantities of others should be added. The carbon and manganese which are essential in steel that is intended to be strong, are prejudicial in steel that is intended to be magnetic. Special steel castings, consisting of almost pure iron, now supply the dynamo builder with a material that is excellent in magnetic quality, and, being cast, they are readily supplied in appropriate shapes for the field-magnets. Special iron or steel is rolled into sheets and stamped into the forms which are wanted for the armatures of dynamos and the cores of transformers, and the magnetic quality which it possesses is immensely superior to that of any iron which could be obtained a few years ago. The testing of iron for magnetic quality, which within my own experience was a matter of original research, is now an everyday operation in the workshop, and iron is ordered to specification of its magnetic properties, just as in other departments of engineering it is ordered to specification of its strength.

In the magnetization of iron we are concerned mainly with two properties—one is permeability, or the readiness with which the metal takes up magnetism, the other is a property to which some eighteen years ago I gave the name of 'hysteresis', after an investigation that was undertaken without any idea that the property in question would come to be commercially important. To understand what happens when iron is magnetized, consider again a ring of iron forming the core on which a magnetizing coil is wound. A current passing through

the coil subjects the ring to magnetizing force, which increases in simple proportion as the current is increased.

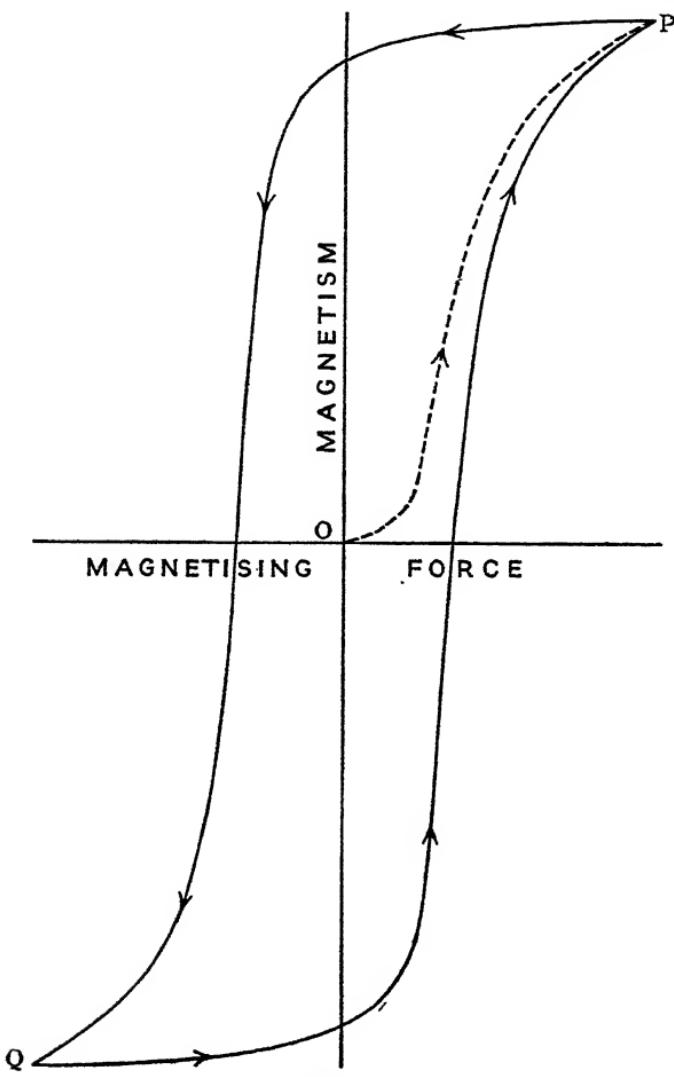


Fig. 1.

But the magnetism induced within the core does not increase proportionately to the magnetizing force. Let

the magnetizing force be gradually raised. At first the increase of magnetism is slow, then very rapid, then slow again. One may observe three more or less clearly marked stages in the process. Thus the permeability of iron is a variable quantity, comparatively small for small magnetizing forces, very large for forces of medium intensity, and then comparatively small again when the force is strong. In all three stages, however, the induced magnetism increases faster than the magnetizing force increases. But by using exceedingly strong forces we find that the metal tends towards a condition in which the increase of magnetism is only equal to the increase of magnetizing force. When that happens the iron is said to be saturated. It then has no greater power of taking additional magnetism than a piece of brass or wood. Engineers have nothing to do with that extreme condition of magnetization. In the transformer and the dynamo we are concerned mainly with what I have here called the first and second stages of the process: these are shown by the broken line in the figure. That line, starting at the zero point O, shows the iron acquiring magnetism until it reaches a strongly magnetic condition at P.

Next, suppose that after the magnetizing force has been raised to any value, it is reduced, say, to zero. We find that the magnetism also becomes reduced, but by no means so much as you might expect. It tends, in great measure, to persist, and a good part of it survives the complete withdrawal of the magnetizing force. Let the process be continued by applying magnetizing force in the opposite direction to the first, and then let the force be again removed and reversed. We thereby get the cyclic process of change from P to Q and back, which is illustrated by the continuous lines PQ and QP in the figure. Throughout this process the changes of magnetism

lag behind the changes of magnetizing force, and it is this lagging behind that is called hysteresis.

Residual magnetization is one of the consequences of hysteresis, and when steel is wanted for permanent magnets the maker has to aim at getting as much hysteresis as possible, which he generally does by putting in some tungsten. But in most of the magnetic uses of iron it is desirable to reduce hysteresis to the uttermost. This is notably true of dynamo armatures and the cores of transformers. In the core of a transformer the magnetism goes through repeated cycles of reversal, such as the cycle shown in the figure, often as frequently as 100 times a second. Now every such cycle means an expenditure of energy, which is greater the greater the hysteresis. It is easy to prove (as was first done by Warburg) that the area enclosed by the two curves which make up the cyclic process is a measure of the work that is spent upon the iron. That work is wasted ; it is simply dissipated as heat. The efficiency of a transformer consequently depends on this more than anything else, that the core should be made of iron having little hysteresis. Various specimens of iron differ very widely in hysteresis as well as in permeability, and hence the practical importance of magnetic tests.

The methods by which the permeability and the hysteresis of iron were at first investigated were laborious, even in the hands of people used to physical research. Several inventors have applied themselves to the task of providing simpler means of making such measurements. Having some personal experience—which began earlier than most people's—in this matter of magnetic testing, I have endeavoured to provide apparatus suitable for workshop use. Some of the instruments devised with this object are before you. One is a Hysteresis Tester, which has come into use for measuring directly the

hysteresis of sheet iron such as is employed in the cores of transformers and dynamo-armatures. The specimen is a little bundle of strips and it is made to revolve between the poles of a permanent magnet which is free to swing upon a knife-edge. At each half-turn the magnetism in the specimen, induced by the permanent magnet, is reversed, and this reversal involves hysteresis, which shows itself by making the magnet become deflected on its knife-edge. The amount of the deflection is read off by a pointer on a scale above, and gives a very simple measure of the hysteresis. The second instrument I call a Permeability Bridge. It allows tests to be made of the permeability of forged iron or cast steel in a way that is analogous to the measurement of resistance by Wheatstone's Bridge. The specimen is turned in the form of a rod, and is tested against a standard rod of the same size whose permeability curve has been determined beforehand. What the bridge actually determines is the ratio of the magnetizing forces which will produce the same magnetic induction in the two rods, and by making this comparison for several different strengths of magnetizing current we have data for drawing the permeability curve for the rod under test. The process performed in this way is somewhat simpler than the older method of testing, and it gives the curve as completely as may be desired.

The various stages in the process of magnetization, and the character of magnetic hysteresis, will be made more intelligible if I show you in action another instrument which I call a Magnetic Curve Tracer, which enables the motion of a small mirror to exhibit magnetic curves upon a screen. The mirror receives two components of motion ; it turns horizontally by amounts which are proportional to the magnetizing force, and vertically by amounts which are proportional to the magnetic induction in a

magnetic circuit of iron which forms part of the machine. Hence a spot of light reflected on the screen from the mirror traces out a curve which shows how the induction changes as the magnetizing force is changed. By reversing the magnetizing current repeatedly we make the iron go over and over again through a cyclic process of magnetic reversal, with the result that the spot of light traces out a closed curve showing hysteresis and having all the characteristics of the cyclic process shown in the figure. The moving parts of the instrument are made very light, so that I can quicken the process sufficiently to make the path of the spot appear, by persistence of vision, as a continuously luminous curve.

There are many interesting features of the magnetizing process on which, if time permitted, we might dwell. Effects of stress and effects of temperature have been very fully examined, with results which, in some particulars, are of practical import. One point which deserves special notice, on account mainly of its physical interest, is that when we change the state of a piece of iron that is being magnetized, whether by heating or cooling, or by pulling, or pushing, or twisting, or vibrating it, the first effect of the change in temperature, or in stress, is to reveal a certain instability in the magnetism, and it is only after several repetitions of the change of state that things settle down and the proper effect of the alteration in condition exhibits itself. This is a phenomenon closely associated with hysteresis, and we shall see presently that the theory which explains hysteresis explains it also.

The effects of temperature on magnetic quality have a direct bearing on some of the engineering applications of magnetism. Some of those effects are immediate, and some only show themselves when the iron has been heated for a considerable time. The immediate effects of heating

have been examined by Hopkinson and others. Briefly, the general effect of heat is to increase the permeability and reduce the hysteresis of iron until a certain critical temperature—about 780°C .—is reached, when iron loses nearly all its power of being magnetized. The change happens somewhat suddenly, for at temperatures only a little lower than that the permeability is very great and the hysteresis exceedingly small. At this critical point there is a big internal change in the molecular structure of the iron, accompanied by a disappearance of heat. The iron, while it is being warmed, suddenly becomes comparatively cool.

Apart from that, engineers are more concerned with the effects of long-continued heating. It was observed that transformers lost some of their efficiency after they had been kept at work for some weeks or months, and that this was due to an increase of hysteresis in the iron core. Mr. Mordey proved that this increase of hysteresis resulted from the prolonged baking of the iron ; a transformer at work becomes warm, largely because of the heat developed through hysteresis, and long exposure to a somewhat high temperature gradually alters the iron for the worse. The amount of this deterioration depends much on the degree of heat, and it is by no means the same for all specimens of iron ; sometimes iron which is at first particularly free of hysteresis is most affected. Mr. Roget, who has investigated the matter in my laboratory, has found that continuous exposure for seven days to a temperature of only 160°C . has actually trebled the hysteresis of one very good specimen ; but, what is most curious, a further continuation of the baking at the same temperature causes improvement to set in. The hysteresis passes a maximum, which comes earlier the higher the temperature of the baking, and then tends to lessen when the baking is further prolonged.

Augmentation of hysteresis is a serious matter in transformers, and much attention has been given to getting iron which will not show it. Some specimens were lately submitted to me which were not only extraordinarily free from this objectionable characteristic, but had much less hysteresis even initially than any iron I had tested before. Makers are naturally reticent as to the process of manufacture by which such results are obtained, and they have in some cases an additional and excellent reason for reticence in the fact that they really do not know what the conditions are to which the good results are to be ascribed. It is probable that light will be thrown on these difficult questions by the application of the microscope, a tool the value of which the metallurgist is now fast coming to recognize.

Much that is obscure in the phenomena of magnetization is made plain when we come to consider what is sometimes called the molecular theory of the process. It is an old idea, due originally to Weber, that the ultimate particles of iron are always magnets, and the process of magnetizing a piece of iron is merely to turn them round so that they face one way. At first they are pointing every way at random, but when magnetizing force is applied they gradually turn, and finally, when saturation is attained, they all lie with their magnetic axes exactly along the line of force. To account for their not all turning at once, and also for the fact of residual magnetism, various hypotheses have been framed, as, for instance, that the turning of each particle is resisted by what may be described as a miniature friction-brake. A good deal of meditation on this matter led me to the conclusion that no such hypothesis was needed. The gradual turning of the little magnets and all the phenomena of hysteresis are simply results of the mutual actions between each of them and its neighbours. We may demonstrate

this by means of a model consisting of a large number of permanently-magnetized needles set on pivots near together. When a weak magnetic field is applied, the pivoted magnets turn slightly and in a quasi-elastic manner, free from hysteresis; but as the field is strengthened the ties between them are overcome and instability ensues, the original groups break up, and the magnets enter into new combinations. Finally, as the applied field becomes stronger still, complete parallelism is gradually approached.

Thus the model reproduces with remarkable fidelity what I have called the three stages of the magnetizing process. Moreover, the dissipation of energy involved in the breaking up of such combinations of little magnets corresponds exactly to what we know of hysteresis. The model shows not only how this cause of hysteresis affects a cyclic process of magnetization, but how it explains the instability which I mentioned as the first thing noticed when we heat, or cool, or stress a piece that is being magnetized. Any change of condition precipitates the breaking up of groups which were, so to speak, hesitating on the verge. By using a model with a large number of little magnets, we get the aggregate external magnetic effect of the group to vary with variations of the field exactly in the way in which the magnetism of iron varies, and the model indicates not only the main, but even the minor features of the process. It was pointed out by Mr. James Swinburne that my theory would involve this curious result, that a piece of iron when revolved in a very strong magnetic field would exhibit no hysteresis, though it shows much hysteresis when revolved in a weaker field. The prediction was experimentally verified by Professor Baily. We may illustrate this in the model by turning round the plate which carries the little pivoted magnets, when you will notice that breakings-up of

groups occur when the field is weak, but not when the field is strong.

I think this model may have a bearing on other physical matters which concern engineers. It is easy to believe that between the ultimate particles of materials there are other polar forces acting, distinct from magnetic forces, and common to non-magnetic as well as magnetic materials. When we make one body slide on another these forces acting across the surface of contact may cause the groups near the surface to become broken up and reconstituted, thereby giving rise to the dissipation of energy with which we are familiar under the name of friction. The action will be apparent if we make one group of the little pivoted magnets slide past another group. We may go further and say that all non-elastic deformation of solid bodies by strain is probably an action of the same kind. Experiments which I have lately carried out, in conjunction with Mr. W. Rosenhain, have shown that the plastic straining of metals occurs through a multitude of separate slippings of one part on another, in each of the crystalline grains of which the metal is made up. The model may be taken as illustrating how in a substance whose particles possess polar forces such slips involve an expenditure of work. But this is taking me away from my already too comprehensive text.

I have tried in this hurried sketch of a great subject to show how in some cases invention has followed as the fruit of discovery, while in others discovery has resulted from the interest created by invention. One word in closing to the student of research. Do not think that in magnetism, because much has been done, nothing is left to do. The upper workings of the mine may be exhausted ; but there are deep levels whose wealth is unexplored. Every point gained is a starting-ground for fresh inquiry.

The patient and intelligent worker may rest assured that his labours will find a return, not perhaps in profit or in fame, but in that impersonal joy of discovery which, as those who have tasted it know, is the investigator's best reward.

1899

To the above Lecture, which was delivered more than thirty years ago, the following note may be appended. It was written in response to a request that I should open a discussion on Magnetism by members of the Physical Society, in 1930. Apart from these remarks, the discussion mainly turned on points of theory relative to such magnetic properties as are shared by other sorts of matter, not belonging to the ferromagnetic group of metals.

DISCUSSION ON MAGNETISM AT THE PHYSICAL
SOCIETY, 1930

OPENING REMARKS BY SIR ALFRED EWING

ABSTRACT. The author reviews briefly his early work on hysteresis in the ferromagnetics, discusses his symbolic models of magnetic structure, and suggests that ferromagnetism affords the most promising source of clues to the outstanding problems of magnetic theory.

As a hopelessly old-fashioned magician, I find it an embarrassing compliment to be asked to open this discussion. You are taking down a dusty piece of apparatus from the upper shelf on which it was long ago put, and inviting it to function. It can do so only in pretty much the old way. I have nothing new to offer. Perhaps the best service I can render is to recall some aspects of the subject which were problems when I began to study magnetism fifty years ago, and are problems still.

My work dealt exclusively with the curious special

group of substances we call ferromagnetics—iron, nickel, cobalt, and their alloys. To these we add a potential fourth member, manganese, because its alloys show ferromagnetic properties. Briefly, the distinguishing characteristics are (1) an immense readiness to be magnetized, (2) saturation, and (3) hysteresis.

Nowadays you are concerned with magnetism as a function of all kinds of matter. But I wish to emphasize the gulf that divides ferromagnetics from other substances. It is a difference in kind, not simply in degree. Of the distinguishing features none is more significant than hysteresis. In my own early experiments it forced itself on my attention at every turn. I became soaked in hysteresis, and was led to invent that name,¹ feeling the need of a word that should be sufficiently wide to include not only the phenomena of magnetic retentiveness, but other manifestations of what seemed to be essentially the same thing, though some of them were not associated with any visible magnetic change. I found, for example, that when a piece of iron or other ferromagnetic metal was subjected to a cycle of stress, as by hanging loads on a wire, and removing and reapplying them repeatedly, the quality of the metal went through a cycle of consequential changes, but irreversibly, being very different at corresponding points in the loading and unloading processes. This is true not only of magnetic quality but of other qualities as well; and it occurs with stresses that are far too small to produce permanent strain. The cyclic changes of stress appear to cause some kind of internal changes of structure, which are cyclic also, but lag statically behind the changes of stress, exhibiting a sort of physical conservatism on the part of the metal—a tendency towards persistence of previous state.

¹ *Proc. R.S.* 33, 22 (1881); 34, 39 (1882); 36, 123 (1883); *Phil. Trans.* 176, 524 (1885); 177, 365 (1886).

That is only one example of the kind of phenomenon which the word hysteresis was intended to cover.

What is the physical cause of this curious lagging ? Here is a problem which you have still to solve. From the fact that it occurs only in ferromagnetic solids one conjectures that it is closely associated with the effects of retentiveness which are observed in the process of magnetization.

The fact of saturation has long ago taught us to think of that process as an orienting of the elementary magnets first imagined by Weber. Each atom has its fixed place in the space-lattice, and we do not now think of the atom itself as turning, for in that case we should expect the cohesion of the substance to be affected, and we know it is not. I have tried the experiment of strongly magnetizing a piece of iron in a testing machine, while it carried a load which very nearly made it yield, and have found that repeated reversals of the magnetism did nothing to reduce the elastic resistance. We must rather think of something within each atom that can turn in response to an applied magnetic force, something which permanently possesses a magnetic moment sufficient to provide the saturation value when in every atom it is brought into parallelism with the applied force.

What controls its turning ? When we begin to apply a magnetic force and gradually increase it we find three stages, always fairly distinct, and capable, under special conditions, of being very sharply separated from one another.

Interpreted as a turning of the Weber elementary magnets, the stages are, first, a small amount of deflection of a reversible kind in which the response to the applied field is slight and is proportional to the field, and there is no hysteresis ; next, a big break-away with irreversible tumbling into new positions of stable equili-

brium, a process which involves much dissipation of energy. There may be more than one successive tumbling from one stable position to another on the way towards saturation. The last stage is again reversible ; it is the final deflection from a stable position into complete parallelism with the applied force. In all this operation it is the tumbling from one position of stability to another that is the essence of hysteresis. It accounts for residual magnetism and for the expenditure of energy in a cycle of magnetization.

Forty years ago¹ I showed that all the characteristic features of the process could be very closely reproduced in a model made up of pivoted compass needles, regularly spaced like the atoms in a crystal lattice, and controlling one another simply by their mutual magnetic forces. Models have gone out of fashion now. My magnetic model was never more than a crude way of showing how hysteresis might be ascribed to the mutual action of parts of the interatomic magnetic system. More recently² I brought it a little nearer actuality, perhaps (though no atomic model can claim to be more than a piece of symbolism), by treating the Weber element as a part of each atom, capable of turning within the atom and controlled by magnetic interaction between itself and the other parts, which were regarded as fixed with respect to the neighbours in the lattice. Here again the control is imagined to depend upon magnetic forces, and we picture each Weber element as being able to respond to an externally applied field, first by a small reversible displacement, then by swinging violently into a new configuration in which it is again stable, but from which it can be displaced by a further increase in the field.

This notion, crude and vague though it is, seems to

¹ *Proc. R.S.* 48, 342 (1890).

² *Proc. R.S.E.* 42, 97 (1922).

me still to point the way towards a clearing of our ideas about ferromagnetism. Shortly after it was first suggested it received an unexpected confirmation, of which I venture to remind you because it has escaped notice in most of the modern books. An acute critic, Mr. James Swinburne,¹ took exception to my idea of magnetic control because it should imply the absence of loss of energy through hysteresis when a piece of iron has its magnetism reversed by the revolution of a very strong field, a field strong enough to secure saturation. For in that case the Weber elements would be held steadily pointing in the direction of the field and would have no opportunity of tumbling from one position of stability to another. It seemed most improbable that there should be so big a difference, in respect of dissipation of energy, between the reversal of magnetism which is brought about by the revolution of a constant strong field and that which is brought about by the reduction of the field to zero and its reapplication in the opposite sense. But soon afterwards it was discovered, through the experiments of Professor Baily,² that this difference does in fact exist. He measured the hysteresis loss caused by a revolving field, and found that for fields of moderate strength there was much loss, but that when the field was made stronger the loss passed through a maximum and rapidly fell almost to zero as the condition of saturation was approached. The whole action turned out to be just such as magnetic control of the Weber element would demand.

These reminders of the past will serve their purpose if they induce some of you, who are naturally engrossed by newer aspects of magnetic theory, to revert to a study of the ferromagnetic group. After all, it is there that

¹ J. Swinburne, *Industries*, Sept. 19, 1890.

² F. G. Baily, *Phil. Trans. A*, 187, 715 (1896).

we have the magnetism of the atom revealing itself on a relatively grand scale, there that we find an attractive tangle of conspicuous magnetic phenomena, and it is there, I think, that we may most profitably search for clues to what is now obscure.

1930

VI

THE WORK OF LORD KELVIN IN TELEGRAPHY AND NAVIGATION

BEING THE SECOND 'KELVIN LECTURE' AT THE
INSTITUTION OF ELECTRICAL ENGINEERS,¹ JANUARY 13,
1910

I

WHEN Lord Kelvin died, on December 17, 1907, he was in his eighty-fourth year. Most of you have some personal impression of him: you have seen him and probably heard him speak. The younger of you have known him only as an old man, still marvellously vigorous and alert for all his weight of years, but none the less enfeebled by age and often distracted by pain. To the last he retained his interest in science, his imagination and insight, his faculty of invention, his sympathy in other men's work. With a fine courage he had accepted the Presidency of this Institution for the third time, in the year of his death. But no one who saw only the venerable figure of these last years can realize the tremendous force, the overwhelming vitality of mind and body that characterized him in his prime. To be with him then was to be as it were in the presence of a whirlwind compelling to activity all who came within its influence. But the comparison, apt as it is in some aspects, fails altogether in another. A whirlwind makes no appeal to the affection, and so

¹ To the original text a few sentences have been added which are taken from a Centenary Address on Lord Kelvin, spoken to the Philosophical Society of Glasgow, October 8, 1924.

the phrase conveys nothing of Lord Kelvin's sweetness and charm. His nature was one of transparent simplicity. He was one of the few very great men whose greatness is not greater than their goodness. To know him well was to love him ; to know him better was to love him more. To work under him was an inspiration. It was not simply that one was amazed by his genius, stimulated by his suggestion or example, infected by his enthusiasm, fired by his untiring energy, moved by his passionate sincerity. He was ever thoughtful for others, encouraging, sympathetic, courteous, modest, reverent. His more tender personal qualities bred a sentiment for which devotion is not too strong a word.

When the Council honoured me with an invitation to give this lecture, I felt it was a task not to be declined. It is fitting that one who had the privilege of assisting Kelvin in the days of his high activity should tell of him to the younger generation. To have known him as he was then is one of the consolations for growing old.

It is just forty years since I first came under his spell. A schoolboy at the time, with an appetite for physical experiments that found but meagre gratification, I happened to be visiting in a house where there were some bound volumes of the magazine *Good Words*, which, as the motto on the title-page said, 'are worth much and cost little'. The motto justified itself to me, for in one of the volumes was an article which went far to determine the current of my life. It was on 'Energy', by Sir William Thomson and Professor Tait, dated 1865—one of the first-fruits of that collaboration which, later, produced Thomson and Tait's *Natural Philosophy*. The article expounded in a simple way the doctrine of the conservation of energy, its capacity for transformation, its tendency towards dissipation. Those ideas were new then, and to me they came with the force of a revelation,

opening my eyes to the unity of physical phenomena. It seemed as if reading the article made such vague and shadowy conceptions as I had in physics and mechanics crystallize into a coherent philosophy. To you, who have been fed on primers in which all these things are treated as established commonplaces, this may be unintelligible ; to me it was very real. You live in the glare of noonday, but it was then the dawn, and it is in the freshness of dawn that one regards the sun. So impressed was I that here was a new gospel, that I copied out the article in manuscript. It had cost nothing, but it was worth much.

A year or two later I went to the University of Edinburgh and attended the lectures of Tait and of Fleeming Jenkin. They imbued their pupils with a wholesome sense of the greatness of Thomson, and I well remember that the introductory lecture of Tait's course referred to a discovery of Thomson's, just then published, regarding the distinctive character of ripples and waves. At the end of the session in 1872 I was invited by Fleeming Jenkin, who, besides being Professor of Engineering at Edinburgh, was Sir William Thomson's partner in consulting work relating to submarine telegraphs, to become one of the firm's assistants. Such a chance was not to be missed. In this way began a personal connection with Kelvin which lasted, on that basis, for several years, and continued on the wider basis of discipleship and friendship to the time of his death.

In later years I have many vivid memories of his visits to the engineering laboratory at Cambridge, sometimes —three times in fact—to perform a ceremonial function such as the opening of the laboratory itself or of a new wing, but much oftener just to see what was going on. It was a joy to show him any research that happened to be in progress, to hear his quick questions, going

straight to the heart of the matter, to have his kindly comment, to witness his unfeigned interest—his enthusiastic delight—when the thing struck him as new and good. His attention and curiosity aroused, he would take no note of time, and the patient Lady Kelvin at his side would try gently to recall the claims of some distant host, some forgotten engagement, some train that should be caught. ‘ You know, William, we *promised* not to be late for lunch.’

The first task of the Kelvin lecturer is one of selection. In the initial lecture, as was fitting, Professor Silvanus Thompson gave an admirable general survey of Kelvin’s life and work. We are glad to think that this will soon be followed by the publication of a biography in two volumes. Professor Thompson has been so kind as to show me advance proofs of his forthcoming work, and to give me access to other material, which has helped much in the preparation of this lecture. May I in thanking him add a word of appreciation of the way in which he has carried out an immense and difficult undertaking? The public will soon be in a position to judge for themselves of the result: they expect much of Professor Thompson, and it is safe to say that they will not be disappointed.

Lord Kelvin’s work was great and many-sided. We might compare it to the cathedral in some crowded mediaeval city where no place can be found commanding a general view. You approach by one narrow street or another, seeing from each only some portion of a particular face of the building. The Kelvin lecturer has, as it were, to select his view-point, conscious that he must concentrate his attention on what is after all but a small part of a gigantic whole. The lecturer might, for instance, take up the mathematical work of Kelvin in the theory of electrostatics, in the theory of magnetism, in the theory of elasticity, in hydrodynamics, in the wave theory of light,

or his contributions to thermodynamics which included the establishment of an absolute scale of temperature and the enunciation of the principle of the dissipation of energy, or again his experimental work on the electrodynamic quality of metals, his speculations on the structure of matter, his views on the age of the earth, his share in fixing the electrical units ; or, on the more practical side, his electrical measuring instruments, from the electrometers of the early days to the ampere balances and wattmeters which he designed when the need for such instruments became apparent with the growth of electrical engineering. Any one of these subjects, or others that might be named, would provide a more than ample text. To-night I have selected two portions of Lord Kelvin's work as the most suitable to bring before you, namely, his work in submarine telegraphy and in navigation. Both of these are practical matters which appeal to members of this Institution. They illustrate well the bent of his genius as an engineer. In both of them he made inventions of first-rate importance—inventions which not only met an immediate requirement, but have stood the test of time. And an additional reason for the selection is the personal one that in both telegraphy and navigation it was my good fortune as one of his young assistants to see some of his inventions in the making.

His connection with telegraphy had begun long before, when he was only thirty years of age. It dates from 1854, and to appreciate rightly the part he began to play then I must ask you to go back as far as 1850, the year of the earliest submarine telegraph. It was in August 1850 that a line consisting of a single copper wire, insulated by gutta-percha, wound on a great reel on the deck of a steam tug in Dover Harbour, was laid from Dover to Calais. There was no sheathing or protection of any sort ; the line was what we should now call a

bare core, and so light was it that lead sinkers were attached at every hundred yards to ensure its going to the bottom. In a few hours it was cut by the anchor of a fisherman, who took home a piece to show to his family as a curious new kind of seaweed, but during its brief life it gave the operators much food for thought. Accustomed only to the clear, sharp signals of land lines, they could make nothing of those got from the cable, and Mr. Willoughby Smith tells us how at each end of the line it was regretfully concluded that the operator at the other end must have been lunching not wisely but too well. This was the earliest experience of the effects of electrostatic induction in retarding the signals and altering their character. The cable is equivalent to an extended Leyden jar of large capacity, and at every application of the sending battery there is a gradual charging up, so that the signal current which arrives at the distant end does not at once reach its full strength. And, further, when the contact with the sending battery stops, the current does not at once cease, but tails off slowly as the cable discharges the electricity it has accumulated. The current accordingly arrives in the character of a wave, slowly rising to a maximum value and then slowly subsiding, each time a signal is sent.

In a short cable this causes little trouble; it only makes the process of signalling a little slower, and the instruments which serve on land lines may still be used. A successful Dover-Calais cable properly covered with a protecting sheath was laid in 1851 and was soon followed by other short lines. The general character of the electrostatic charge in a cable was explained by Faraday, and it was experimented on by Latimer Clark in a cable, 110 miles long, laid to connect England with Holland. But no one knew then in what manner the retardation of signals to which it gives rise depended on the electrical

characteristics, nor how it would be affected in cables of different lengths or with different dimensions of core. It was in 1854 that Thomson's attention was drawn to the subject by Stokes, following on a conversation at the British Association, and in this way began the connection with submarine telegraphy which was to prove of momentous import.

You must think of Thomson then as a young man of thirty—already for eight years a Professor at Glasgow—unknown to the general public, but with a European reputation among scientific men for his far-reaching investigations in the mathematical theory of electricity and in thermodynamics. Helmholtz, whom he met for the first time a few months later, thus records the impression he produced : ‘ I expected to find the man who is one of the first mathematical physicists of Europe somewhat older than myself, and was not a little astonished when a very juvenile and exceedingly fair youth, who looked quite girlish, came forward. . . . He far exceeds all the great men of science with whom I have made personal acquaintance, in intelligence and lucidity and mobility of thought, so that I felt quite wooden beside him sometimes.’

Thomson attacked the problem with characteristic ardour, and in less than twelve days he sent a complete solution to Stokes, which was published in fuller form in the Proceedings of the Royal Society for May 1855. In this paper he points out that the effect of electrostatic induction is to make the flow of electricity in a cable correspond to the flow of heat in a solid conductor as investigated mathematically by Fourier. He formulates the equations and draws what is called the *curve of arrival*, the curve, namely, which shows in what manner the current gradually reaches its full value, at the distant end of the cable, when contact with the battery is made

at the sending end. He also shows how the current falls away when the battery is removed and the cable is put to earth. In the diagram (Fig. 1) the full line is the curve of arrival. For a certain interval a after the battery is connected almost no effect can be observed, but soon after that the current becomes of sensible magnitude. It continues to rise; and after a time nearly equal to $5a$ it has

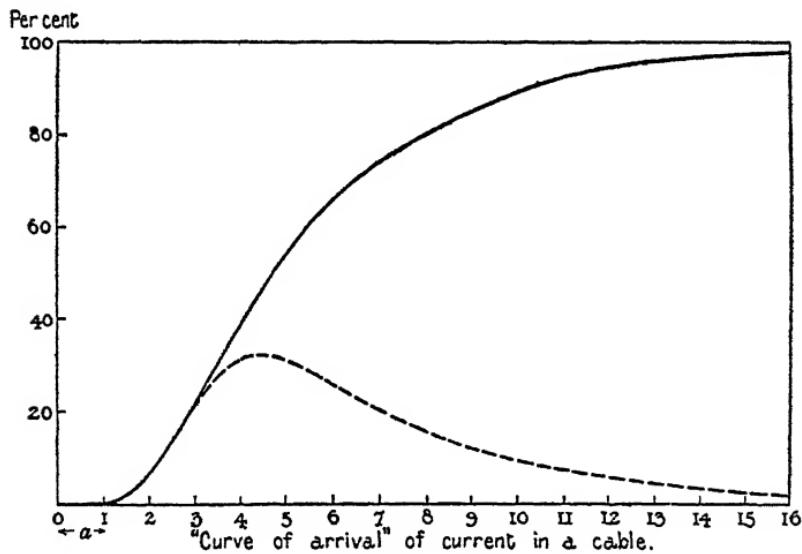


Fig. 1.

come within 10 per cent. of the final value, and its rise has then become very slow. To reach completely the full value an infinitely long time would be required. The dotted line shows how the current at the distant end decreases when the sending end is removed from the battery and put to earth. In this case the contact has lasted for the interval $3a$. When it ceases the current at first continues to increase, soon passes a maximum, and then gradually tails away, requiring an infinitely long time altogether to disappear.

Thomson showed that the quantity a varies directly as the product of the capacity of the cable and its resistance. Since both the capacity and the resistance increase directly with the length, if we compare two cables with the same core but of different lengths, a will depend on the square of the length. Hence also the time taken by the current to reach any particular fraction of the full value will vary as the square of the length.

This result of the theory was of fundamental importance. It was also, at the time, of particular interest, for the project was then beginning to be mooted of connecting England and America by wire. The only experience available as to speed of signalling was on short cables, and in passing from them to a line two thousand miles long the ' law of squares ', as it was called, seemed at first to give little prospect that signalling across the Atlantic could be accomplished at a speed that would be commercially practicable. The ' law of squares ' was challenged by Mr. Whitehouse, who was interested in the Atlantic project. He failed to grasp Thomson's reasoning and its results, and misinterpreted some experiments of his own in a sense opposed to Thomson's theory. Thomson replied in two letters to the *Athenæum* (October and November 1856), pointing out that Whitehouse's experiments, so far as they went, only tended to confirm his own conclusions, and emphasizing the fact that a remedy for inconvenient slowness of action was to be found partly by increasing the diameter of the conductor, thereby reducing the resistance, and partly by increasing the diameter of the gutta-percha coat, thereby reducing the capacity. It appears to have been these controversial letters which led to Thomson's taking a share in the earliest attempt to lay an Atlantic cable, the attempt of 1857.

Two practical points at once engaged his attention. One was the question of copper resistance. ' In measur-

ing the resistance of wires manufactured for submarine telegraphs,' he writes in June 1857, 'I was surprised to find differences between different specimens so great as most materially to affect their value in the electrical operations for which they are designed.' He looked at first for an explanation of these differences in the stranding of the wires or in the effect of covering with gutta-percha, but after various experiments (his laboratory was then a disused wine-cellar in the old Glasgow College) he was forced to the conclusion that the differences lay in the nature of the copper itself: that one might find specimens with twice or even more than twice the resistance of the best. Having discovered in this way the distinction between high conductivity copper and copper of other sorts, he insisted on the use of copper of the highest conductivity and on the importance of systematic testing, though this came too late to affect the manufacture of the cable which was being prepared for the abortive attempt of 1857.

The other point which he took up was the invention of a method of signalling adapted to the character of the 'curve of arrival'. But before speaking of that, let me say a word as to his position among the Atlantic cable pioneers.

The Atlantic Telegraph Company had been formed in October 1856, and in December Thomson joined the Board as one of the directors, elected to represent the interests of Scottish shareholders. Charles Bright was engineer-in-chief, and Whitehouse, who had misunderstood and disputed Thomson's electrical results, was electrician. Thomson had no technical position beyond being a director. Writing to Helmholtz in December 1856, he says: 'The Atlantic Telegraph is now in the process of manufacture. Two thousand five hundred miles of cable are to be finished and ready to go to sea by the end of May, and if no accident happens electric

messages will be passing between Ireland and Newfoundland before July. I have been appointed one of the directors, and what I feel most anxious about now is the laying of the cable. The plans must be better arranged than they have been in all such operations hitherto, in which there have been almost as many failures as successes. However, the circumstances are in some respects more favourable than they have been in former cases. We have a soft level bottom (consisting of fine sand and microscopic shells) the whole way across, nowhere more than $3\frac{1}{2}$ miles deep, which will be much better than the Alpine precipices and valleys below the waters of the Mediterranean. The cable is much lighter than any hitherto laid, weighing only 18 cwt. per mile, or in water only 10 cwt. The practical men engaged have all the experience of previous failures, and it is to be hoped have learnt some of the causes and will know how to avoid them. Altogether I think there is a good chance of success.'

That hope was not destined to be immediately fulfilled. To lay the cable it was coiled on board two ships of war, the British battleship *Agamemnon* and the United States frigate *Niagara*. On August 5, 1857, the shore end was landed at Valentia and the *Niagara* began to pay out, the intention being that her section should be laid first and the *Agamemnon* should continue the work after making a splice in mid-ocean. But the paying-out gear was very crude : the brake for maintaining a proper tension in the cable was difficult to regulate, and after three hundred miles were laid there was a mishap at the brake and the cable parted in two thousand fathoms. The ships returned to Devonport : the cable was stored for the winter, new machinery was designed, and some seven hundred miles of fresh cable were manufactured against the next attempt, to be made in the following year.

Thomson had joined the expedition at the request of his brother directors and was on board the *Agamemnon*. He came back full of ideas as to both the electrical and the mechanical sides of the great problem.

On the mechanical side he had worked out, for the first time, the theory of the forces concerned in the laying and lifting of deep-sea cables ; this was published almost immediately after his return. Let me give you a brief sketch of the results of this theory.

A cable paid out from a ship going at uniform speed does not hang as a catenary but takes the form, as it sinks, of a straight line stretching at a uniform slope from the ship's wake to the point far in the rear at which it touches the bottom. This is because each part of the cable in sinking through the water attains almost immediately a constant velocity of descent against the resistance which the water opposes to its motion. Imagine a ball, heavier than water, to be dropped from a ship. It will after sinking a foot or two attain a practically uniform velocity and keep that until it reaches the bottom. Imagine now a ship to drop a series of such balls, at regular intervals, while she steams ahead at a steady speed. At any instant the depth through which each ball has sunk will be proportional to the time which has passed since it was dropped, and therefore to the distance run by the ship, and hence a line joining the successive balls will be a line of uniform slope. The continuous cable behaves in this respect like the row of balls, but with this important difference. Each ball sinks vertically, it has no tendency to do anything else. But the cable tends not only to sink, but to glide along the direction of its own length, just as a rope resting on an inclined plane tends to glide down it. A certain amount of such gliding is desirable, indeed necessary, for it secures that the cable will be laid with a sufficient percentage of slack to accom-

modate itself to any inequalities on the bottom, and to provide for the possibility of its being raised, should that be required. It is the function of the paying-out brake to apply just so much retarding force as will allow the right amount of this gliding to take place, and not too much. Taking any point P in the cable (Fig. 2), the actual motion in settling to the bottom may be regarded as made up of two components, one a component transverse to the direction in which the cable lies (P M) and the other the longitudinal or gliding component P N along that direction. The result is to give a resultant motion which brings the point P along the line P R to

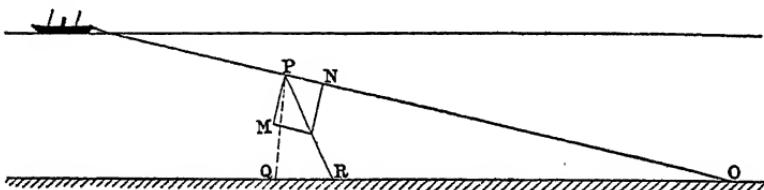


Fig. 2.

the bottom at R. If there were no slack, the movement would be along P Q, where O Q = O P. As cables are actually laid there may be 10 or 12 per cent. of slack, and this means a considerable velocity of gliding motion. In a cable of the type which was afterwards successfully laid across the Atlantic the straight line had a slope of about 1 in $8\frac{1}{2}$ —in other words, with a depth of 2 miles there were 17 miles from the ship to the place where it touched bottom. In the gliding motion down this long slope the frictional resistance of the water is an important factor: it reduces very much the retarding force needed at the brake. If it were simply a question of holding the cable from gliding down the slope at all, the retarding force would be equal to the weight, in water, of a length of cable equal to the depth. In fact, however, it is about

half that, the other half being accounted for by the frictional resistance which the cable experiences in gliding down the slope.

In the early summer of 1858 the cable squadron was again ready to put to sea. New paying-out brakes had been devised. Thomson had succeeded, with much difficulty, in getting systematic tests of the conductivity established during the manufacture of the additional seven hundred miles. And, most important of all, he had invented a new signalling and testing instrument which was to make Atlantic telegraphy commercially practicable. This was the mirror galvanometer, the first description of which is found in his patent of 1858. Mr. Whitehouse, still officially the electrician of the Company, had provided an elaborate paraphernalia of relays and induction-coils which experience was to prove useless. Just before the ship sailed there was handed to Thomson on board the *Agamemnon* a precious package brought hot-foot from Glasgow by his assistant, Donald Macfarlane. This was the earliest marine mirror galvanometer—one of a pair completed only just in time. The other went to the *Niagara*. It is now preserved in the museum of the Glasgow University laboratory. I am able to show you a photograph of the actual instrument by which a message was first received across the Atlantic.

In its simple form the mirror galvanometer consists of a tiny circular glass mirror no bigger than a threepenny piece, to the back of which are cemented two or three pieces of steel watch-spring flattened and hardened and permanently magnetized. This is hung by a silk fibre in a horizontal tube a little bigger than the mirror itself; the suspending fibre, which is quite short, passes out at a hole in the upper side of the tube, and is secured there by a drop of wax or cement. Mirror and magnets together weigh less than a grain. The tube, with the mirror

in it, is pushed into the centre of a coil through which the current passes. Outside there is an adjustable magnet, or pair of magnets, to give a suitable controlling field. A beam of light from a lamp falls on the mirror and is reflected on a scale. Thus we have, as it were, a very long pointer to exhibit the deflection, entirely destitute of inertia. The marine form differs only in the method of suspending the mirror. The suspender is a long thread held tight at top and bottom, to the middle of which the mirror is attached. This makes it independent of gravity,

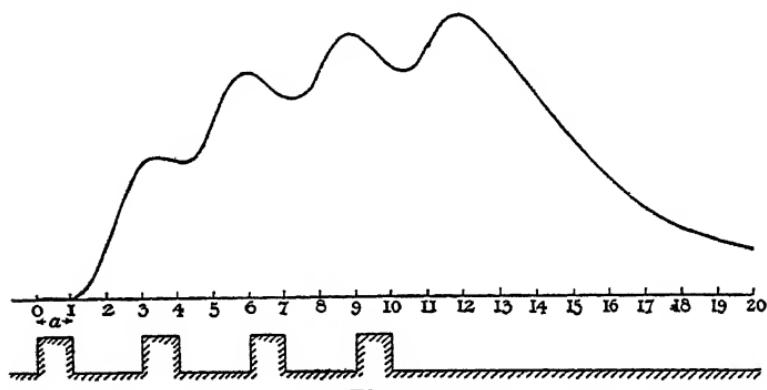


Fig. 3.

so that it is not disturbed by the motion of the ship. The instrument is sensitive in responding to the slightest current or fluctuation of current: there is no friction to be overcome, and almost no inertia in the moving parts.

These are the characteristics which Thomson aimed at in this remarkable invention, for he saw that they were required as a direct result of his theory.

Go back to the 'curve of arrival', and you will notice that to make rapid signalling practicable, we must be content to deal with only the earliest stages in that curve. Even in later Atlantic cables the time unit a is

about the fifth of a second : in the original cable of 1858 it was much longer. If the transmission of a signal required a time equivalent to many times a the number of words got through per hour would be impractically small. Hence also the impulses constituting successive signals must follow so quickly on one another's heels that the cable has no chance to get rid of the effects of one before the next is upon it, and the next. Take, for

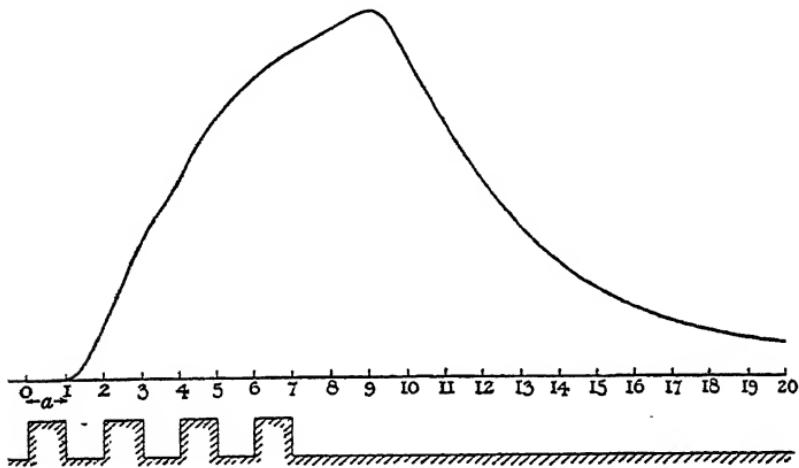


Fig. 4.

example, the letter *h* consisting of four successive impulses of the same sign. If we were to form each of them by a battery contact for the period a , followed by an earth contact for the period of $2a$, we should get a curve of arrival like the figure (Fig. 3), where you see well this superposition of effects ; and if we try to quicken up the speed by reducing the earth contact to a as in Fig. 4, the confusion becomes so great that it takes a practised eye to distinguish that there are four impulses in the resulting curve. To exhibit these as signals it was clearly impossible to use an instrument like an electromagnetic relay of even the most sensitive type : you must have

an indicator which will follow every fluctuation in strict proportion, not requiring to come back to zero between the impulses ; it must be frictionless, and it must not introduce any distortion by virtue of the inertia of its own moving parts. This Thomson achieved by his invention.

We have still to complete the story of the cable of 1858. This time the two ships, after encountering a storm of great severity in which the coiled cable suffered severe damage, met in mid-ocean, spliced the cable, and began to pay out simultaneously, the *Agamemnon* steaming towards Ireland and the *Niagara* towards Newfoundland. The cable broke when only six miles were paid out. Again the ships met, to make a fresh splice, and again the cable failed when some eighty miles had run out. A third attempt promised better, for some two hundred miles were laid, when again the cable broke, at a place where it had been injured in the storm. The ships returned to Queenstown : Bright, Thomson, and the other leaders, disappointed but not disheartened, advised the Board to order a fresh attempt. Their advice was taken. The ships once more met at the mid-ocean rendezvous, and this time success crowned their efforts. On August 5 both ships completed their task, and the ends of the cable were brought to land.

Scarcely had the enthusiasm awakened by this great event begun to subside when it was apparent that all was not well. The Irish end of the cable had been handed over to Mr. Whitehouse, who attempted with little or no success to establish communication by means of his own signalling instruments. It was only when the galvanometer of Thomson was resorted to with a simple Daniell battery to send the current that messages were transmitted. The Board, dissatisfied with Whitehouse's action, directed Thomson to take complete charge. Various

important messages passed, but the tests showed that the insulation of the cable had broken down : a bad fault developed, which had doubtless been intensified if not produced by the high-tension induction-coils used by Whitehouse. The signals grew more and more feeble, and in a few weeks the cable altogether ceased to speak.

It never spoke again, and not till 1865 was the attempt made to lay a new Atlantic cable. By that time much had been accomplished. It was in the intervening years that the work of establishing standards for electrical measurement was undertaken by a Committee of the British Association. The Committee was appointed at the instance of Thomson, and he took a prominent part in its work. Besides this, the cable engineers were busy and were gaining experience from lines laid in other places. Methods of systematic testing were devised : a type of cable was designed which was better adapted than before to bear the strain of laying, and especially the much severer strain of picking up, and material improvements were made in the paying-out machinery.

Thomson encouraged a fresh attempt. 'What has been done,' he said, 'will be done again. The loss of a position gained is an event unknown in the history of man's struggle with the forces of inanimate Nature.' On the financial side it required some faith and courage to engage in the enterprise at a time when it was said that out of nine thousand miles of cables already laid, only three thousand were in working order. We cannot wonder that there was some delay.

In 1865 the *Great Eastern* was available for laying the cable. Thomson, along with Cromwell Varley, went as a consulting expert on behalf of the Company. Twelve hundred miles were successfully laid, and then a fault showed itself : picking up was begun, but in manoeuvring the ship the cable parted in deep water. Attempts were

made to recover it by grappling ; three times it was hooked and brought part of the way to the surface, but the shackles used to couple up successive lengths of the grappling rope were too weak to stand the strain. Grapnel, rope, and cable were lost, and the ship returned with the task unfinished, but with every one now full of confidence not only that a sound cable could be laid, but that the lost cable could be found and lifted.

In 1866 the thing was done ; an entirely new cable was laid with complete success, and then the *Great Eastern* with her consorts proceeded to the lost end of the cable of 1865, and began once more to fish in water over two thousand fathoms deep. A fortnight passed before the watchers at Valentia saw any sign : then the spot of light began to flicker, and presently the flickerings shaped themselves into letters and words. The cable had awokened to life. A few days more and it too was complete.

Throughout the operations Thomson was in the ship ; Varley remained at Valentia. Thanks to their labours, and to those of Mr. Willoughby Smith, the contractors' electrician, the appliances for testing on board ship had been brought to a degree of perfection that left nothing to be desired. By this time it was generally recognized that the credit for Atlantic telegraphy, regarded as an electrical achievement, belonged to Thomson, though in his characteristic manner he would, when speaking of the subject, dwell on the parts played by others. Along with Mr. Canning, the engineer of the expedition, and Captain Anderson, who commanded the *Great Eastern*, he received the honour of knighthood.¹

For a time his mirror galvanometer remained the only instrument by which conversation could be carried on.

¹ Sir Charles Bright, who was engineer-in-chief in the earlier expeditions, did not take part in the expeditions of 1865-6, but continued to advise one of the companies concerned. He was knighted on the completion of the 1858 cable.

He soon proceeded to design a substitute for it, which should give a record of the successive electric impulses instead of merely exhibiting them to the watchful eye of a skilled clerk. To secure greater power in the movement of the indicator he inverted the function of magnet and coil, making the coil the movable piece and the magnet the fixed piece. The coil was, therefore, made very light : the magnet, which being stationary might now be very heavy, was made exceedingly strong and was arranged so that the coil lay in an intense field between its poles. The movement of the coil actuated a very light pointer or rather pen in the form of a siphon-shaped tube of fine drawn glass, from which ink was deposited on a running paper band. Here we find the earliest example of the moving-coil type of galvanometer, often called the D'Arsonval type by those who do not recognize its real origin. It is a type now familiar in many practical instruments for the measurement of amperes and volts. But an important element in the invention is still to be named. It was essential that the glass pen should write without friction, and Thomson effected this by the happy device of electrifying the ink so that the ink and the paper attracted one another, with the result that the siphon was maintained in a constant state of rapid vibration, alternately advancing to the paper to deposit a minute drop of ink and then springing back, but all the time free to follow without friction the movements of the coil in obedience to the electric impulses arriving through the cable. Dynamically the siphon recorder has to satisfy the same conditions as those that determined the design of the mirror galvanometer. It draws on the moving strip of paper a curve of arrival for every one of the successive currents of which the signals are composed.

To this day the recorder remains in universal use as the standard instrument in submarine telegraphy. It

has been simplified by the substitution of permanent field-magnets for electromagnets, and by the use of an electromagnetic vibrator for the siphon instead of electrification—changes which were made in later years by Thomson himself.

Thomson was now beginning to reap some reward for his inventions. He had formed, in 1865, a partnership for telegraphic patents with Cromwell Varley and Fleeming Jenkin. Varley's chief contribution was the highly important device of signalling through condensers, and Jenkin was associated with Thomson in the invention of what is known as 'curb sending'. This is a method of sharpening the signals through a cable by following up each signal-current with a reversed current of somewhat shorter duration, instead of putting the cable to earth, the effect being to get as it were a quicker emptying of the cable in preparation for the next charge.

Besides the triple partnership of Thomson, Varley, and Jenkin in patents there was a separate partnership between Thomson and Jenkin which lasted until Jenkin's death, under which they acted as consulting engineers for the construction and laying of submarine cables. Among the cables for which they acted were the Western and Brazilian line, the first section of which was laid in 1873 by the steamship *Hooper*, a ship specially built for cable-laying with what was for those days a phenomenally large capacity. I recall a voyage of the *Hooper* when in mid-ocean she dropped one of the two blades of her single screw : she completed the round trip to Rio Janeiro and back, including the laying of the cable, on a single blade ; and it puzzled us youngsters to understand how the run, the day after the blade was dropped, was better than any run made before ! Sir William Thomson went out in the *Hooper* on her first trip, and at Madeira, where there was some delay through the cable having to be

turned over in the tanks to cut out a fault, he met the lady who afterwards became his wife. In teaching her the Morse alphabet the acquaintance ripened fast. Thomson was at that time an ardent advocate of the use of Morse by occulting lamps and other devices as a means of communicating intelligence at sea. In one of his letters home he says : ' We had some admirable lamp signalling several evenings at Funchal between the *Hooper* and Mr. Blandy's house about $1\frac{1}{2}$ miles distant. The Miss Blandys learnt Morse very well and quickly, and both sent and read long telegrams the first evening they tried it, to the admiration of France and other old telegraphers on board.' Next year he returned to Madeira in his yacht and, Viking-like, captured Miss Frances Blandy and brought her home as his bride. Those of you who have known Lady Kelvin do not need to be told how happy a chance this meeting proved to be, nor how much he owed, throughout all the remainder of his life, to her understanding sympathy and unceasing solicitude.

Those were days when the testing-room of the cable factory was a better school in which to learn electricity than any laboratory. Practice, which owes so much to science, was just then giving back, in that department of knowledge, as much as she received, or more. The electricity of the workshop had outstripped the electricity of the schools : it had become more scientific than the electricity of the lecture-room and of the text-book. Members of this Institution have no need to be ashamed of the heritage that has come to them from the earlier Association from which this one sprang—the Society of Telegraph Engineers. To the telegraph engineer of the sixties and seventies is due most of the exact measurement and much of the exact thinking which supplies the foundation of the electrical engineering of to-day.

I well remember how, when Thomson periodically

visited London to inspect the progress of the work, one of us would meet him at Euston to accompany him in the cab, telling him results of the tests, and receiving instructions, so that none of his precious minutes should be lost. Later, when I was working mainly in Edinburgh with Fleeming Jenkin, Thomson's visits from Glasgow were thrilling events. He was then President of the Royal Society of Edinburgh, a lively central figure in it and author of many communications. After the meetings he would occasionally take me on to the Evening Club, where I would sit silently receptive, while Tait and Crum Brown and other giants talked with him and smoked churchwarden pipes. Except for such placid moments my memories of those visits are memories of hurry and distraction.

Sometimes I went to Glasgow to discuss business with him or to make some test in his laboratory. I recall vividly the quick lame step, the penetrating criticism, the generous appreciation. There were visits to James White's shop in Sauchiehall Street, where, passing at once into the little workshop behind, he would give his directions to the instrument-maker and scribble on a torn envelope the only 'working-drawing' that in those days ever helped to bring his inventions to the birth. I recall too, in his own house, the frequent fits of abstraction, when, pulling out of his pocket the green quarto note-book that was always there, he would bury himself in some calculation, oblivious, as it appeared, of what was going on around, neglectful even of his favourite parrot's repeated invitations to join in the whistling of a part song. It was that observant bird which was so often driven to exclaim, in accents of well-merited reproach: 'Late again, Sir William.'

Often one met there his elder brother James, a man of exceptional originality and independence of thought, to

whom science owes several notable advances. In more than one instance, the suggestions of James afforded a foundation on which the quicker and more comprehensive brain of William proceeded to build. Between the brothers there was much affectionate intercourse. In later life it was pretty to see William's deference to his brother's opinion, his eagerness to bring James forward and have his genius (for it *was* genius) properly recognized. And it was also, sometimes, difficult not to be impatient ; for James, great as was his insight, seemed wanting in some sort of mental perspective, and had very little sense of time. There was never a flaw in his logic ; it was devastatingly thorough and would tolerate no admission of even the most obvious preliminaries. Occasionally one listened to his argument as the wedding guest listened to the tale of the ancient mariner, wondering not so much when it would end as when it would really begin. I remember his once holding me, at a delightful evening party, while he discoursed upon the dynamical consequences which were being produced on the earth's rotation and the position of its axis in space, by the motion of the couples who were then gyrating in his drawing-room. It was no doubt an interesting problem, but I was at an age when there was more enjoyment to be got by taking part in the operation than by listening to a discussion of its cosmical effects.

I have spoken of the earlier association of Thomson with Fleeming Jenkin in telegraph work, in patents, and in the determination of the electrical units. Here are a few reminiscences which have been kindly sent me by Mrs. Fleeming Jenkin :

' My recollections date from the autumn of 1859, when I first saw him. Fleeming had told me much about him, speaking of him with great affection, but also with awestruck admiration and veneration, so that I pictured

to myself Professor Thomson as an aged and severe philosopher and rather dreaded an introduction to him. One evening I was sitting reading by lamplight, when I heard hurried steps coming up the stairs: the door opened and in came a tall, fair-haired young man, who, not waiting to be announced, said with a most radiant smile, "Where is Fleeming? Are you his wife? I must see him. I am William Thomson." Then he spoke a few kind words of congratulation on my recent marriage, and I saw for the first time that benevolent bending of his eyes on the person to whom he spoke that always remained, and increased, I think, with the years. But the splendid buoyancy and radiance, which made me say to my husband when he came in later, "I have had a visit from Professor Apollo," I never saw again. It was in the following winter that Professor Thomson met with the accident which lamed him for life.

' From that time forward I often saw Professor Thomson. He and Fleeming were experimenting together on submarine telegraphic instruments. As Professor Thomson lived in Glasgow, our house in London became the place where the experiments were carried on, and our dining-room the workshop. Gradually, as the number of instruments increased, our dining space became smaller, till I seem, remembering, to see Professor Thomson and Fleeming and me dining together hurriedly on a little island in the middle of the room, surrounded by an ever rising tide of galvanometers, coils of wire, and mechanism of all sorts. After dinner they used to set to work and work for hours. I used to make coffee and tea and carry it in to them from time to time, and sometimes I was trusted to sit with a watch in my hand and count the seconds between one flitting flash of light and the next on the instrument then in hand.

' I say we dined hurriedly, because Lord Kelvin always did, or seemed to me always to do, everything at top-most speed. When he came, it was always in a hansom cab, in front of which he stood, urging the driver on and

guiding him by his pointing stick to our house, the address of which he never could learn though he came thither constantly, and when he went he was whirled away just in time to catch some mysterious train which started for Glasgow at the earliest possible hour in the morning.

' He loved music and would listen to it in a sort of trance of enjoyment. But at this time he would admit none but German music to be music, and used vehemently to attack Italian music, which we admired. It happened, a day or two after such a discussion, that we had an opera box sent us. The piece was Rossini's "Semiramide". Professor Thomson arrived to dine and work as usual, but we carried him off to the opera, but did not say what opera was to be given. We were a few minutes late, and as we took our seats Trebelli began her great song. He listened in rapture and at the end said "Beautiful". I held the play-bill out to him, pointing to the name of the composer, "Rossini". "Ah!" said he, "but it *was* beautiful and I was wrong".

' One more recollection is of a luncheon party at our house, to which he came ; a very learned luncheon party ; there were three Senior Wranglers present at it. The talk turned, not unnaturally, on scientific matters ; Sir William, to illustrate what he said, and to prove that if a tumbler full of water were turned upside down in a certain way, the water would not come out, took a tumbler, filled it, turned it upside down—and all the water poured down on to the table. Murmuring "Some error", he filled it again, turned it upside down again, and down came the water again, so that the table was all aswim. Terribly sorry and begging pardon in his kindest way, he became flurried and dropped the tumbler, which broke in pieces. He was inconsolable and insisted on driving round by a shop on his way to the station to buy me a tumbler in place of the broken one. In the greatest hurry, and in spite of all we could say, he caught up the broken pieces to match them and drove off. Soon he came back in triumph, waving a tumbler from the

cab window. Fleeming ran out to receive it : Sir William drove off : Fleeming brought in the tumbler : it did not match !

' And then the last time I saw him, not many months before his death, when his kindness and courtesy were, if possible, more beautiful than ever : when he insisted on giving me his arm and bringing me out to the carriage I was in, though he was so weak and worn with pain and age.'

II

It is time now to turn to Lord Kelvin's work in Navigation. He loved the sea. ' I am a sailor at heart,' he said of himself, and for many years he delighted to escape to his yacht, the *Lalla Rookh*, not indeed to take holiday as other men understand it, but to find seclusion for scientific work. In all that concerned the art of the navigator his interest was practical and keen. And this with him meant an impulse to improve the art. *Nihil tetigit quod non ornavit.* Taking the two oldest aids to navigation, the compass and the sounding-line, he revolutionized them both. Where most men would have thought there was nothing left for invention to do he found much. He has earned profound gratitude for appliances which add immeasurably to the security of all who go to sea. He has been called the best friend the sailor ever had ; it is said that a blue-jacket was once overheard to remark, ' I don't know who this Thomson may be, but every sailor ought to pray for him every night.'

It was about 1873 that he began to study the compass seriously, partly because he had undertaken to write an article on it for *Good Words*, and partly because he had occasion to prepare, for the Royal Society, a biographical sketch of his friend Archibald Smith, containing an account of Smith's work on the theory of the per-

turbation of the compass caused by the magnetism of iron ships. Kelvin's first patent for an improved compass was taken out in 1876.

He found the compass full of serious defects. For one thing it was very unsteady—that is to say, it was liable to be set swinging through a large angle when the ship rolled. Sometimes an attempt was made to reduce this unsteadiness by introducing friction at the pivot, which, in a way, made matters worse by causing the compass to stick, pointing in a wrong direction. Under a mistaken idea of what would lead to steadiness, the card was made heavy and the needles long ; and the long needles made it impossible to correct the compass properly for the magnetism of the ship. This was the most serious defect of all. In iron ships, and especially in ironclads, the compass is at the mercy of disturbing influences which do much to mask the true directive force of the earth's magnetic field. To neutralize these is indispensable : the way to do it, as a matter of theory, had been pointed out, but it was only through the radical changes in construction which we owe to Kelvin that it became possible to carry the neutralizing process into effect.

He recognized that for this purpose the needles must be short. Further, that for steadiness what was wanted was a long period of horizontal oscillation—in other words, small magnetic moment relatively to the moment of inertia of the card. But, to keep the frictional error down, the weight of the card, including the needles, should be small. So he made the card as light as he could get it ; a mere aluminium rim tied by silk threads to a small central boss, just as the rim of a bicycle wheel is tied to the nave by wire spokes ; and from the silk-thread spokes he hung short pieces of magnetized knitting needle to serve as the magnets. The result was that not only was the total weight very small, but it was nearly

all in the rim, where it is most useful for giving moment of inertia and consequent slowness of period. Magnets and all, the card only weighs 180 grains, for a 10-inch size, and yet its period of oscillation is much longer than that of the old standard compass, while its friction error is less. Its gossamer structure puzzled navigators accustomed to earlier forms. I have been told of Lord Kelvin's once showing it to a committee of admirals who were disposed to say, 'Too flimsy; sure to be fragile.' His reply was to throw it across the room. It took no harm, and one version of the story says that he threw after it what was then the Admiralty standard card—a vastly heavier structure—with disastrous results.

Another admirable feature of Kelvin's invention was his method of keeping the compass always level and free from pendulum-like oscillation. He hung the bowl, as usual, from gimbals, but with knife-edges instead of the usual round spindles at the trunnions, and under the card he provided a chamber at the bottom of the bowl partly filled with castor-oil. You see this in the glass bowl now on the table. There is a glass partition to separate the place where the compass card stands from the lower part of the bowl, and in the lower part is the castor-oil. Its function is to damp out any oscillation of the bowl that may tend to be set up by the rolling or pitching of the ship, and it does so by dissipating the energy of such swings. At the same time the knife-edge gimbals leave the compass perfectly free to take up a true level.

Another feature is that the bowl and gimbals as a whole is hung from springs to withstand vibration caused by the action of the screw, or in warships by gun-fire.

Now as to the correction for the magnetism of the ship. Let me indicate very briefly the nature of that problem, and how it is solved.

An iron ship is a great magnet, or rather a great aggregate of many magnets. Her magnetism at any instant springs from two causes. First there is the more or less permanent part, which she takes up to begin with when she is built: it depends to a great extent on how her head lay while she was on the stocks. Then there is the induced part which changes with every change of course: a transient effect due to the induction of the earth's magnetic field. Strictly speaking the induced magnetism is not entirely transient, nor is the other by any means entirely permanent; but the ideal division into transient and permanent is a highly useful one provided we understand the limitations within which it is to be accepted. Now think of what happens when the ship is 'swung'—that is, turned so that she heads successively on all points. The permanent magnetism will cause an error of the compass which will be of the same nature as you would find if you placed a compass needle on a fixed pivot, and disturbed it by turning a bar magnet slowly round a vertical axis. This error will reach a maximum twice in the revolution—once to one side and once to the other side—in other words, once in each semicircle. Hence it is called the semicircular error.

The permanent magnetism of the ship need not, and as a rule will not, be simply in the direction of the length. In general it will be inclined both sideways and up and down, and we may regard it as having three components, one fore and aft, one athwart-ships, and one vertical. All three components contribute to produce semicircular error, and the semicircular error produced by them is corrected by putting permanent correcting magnets underneath the compass, in the binnacle, which are carefully adjusted, so that they produce, at the compass itself, a horizontal magnetic field which exactly balances there the disturbing horizontal field due to the ship's magnetism.

The adjustment is carried out by putting in more or fewer magnetized bars, and placing them at a higher or lower level in the binnacle so that they act more or less strongly on the compass above. One group of the corrector magnets faces fore and aft, and another faces athwart-ships. The fore and aft magnets are adjusted to correct the error that is found when the ship's head is east or west, the 'thwartship' magnets are adjusted to correct the error when the ship's head is north or south.

If the ship remained always on even keel these two sets of horizontal correctors would suffice to correct completely the deviations which are caused by the permanent magnetism of the ship. But when the ship rolls, or when she is permanently heeled over to one side, another kind of error, called the 'heeling error', comes in, which arises from the fact that the ship's magnetism has a vertical component. I am still speaking in the first place of the permanent magnetism of the ship: we shall come to the effects of induced magnetism later. When the ship heels to either side the component that was vertical to begin with becomes inclined, with the result that a new deviating force comes into play. Say, for example, that the ship has been built in England or in any other northern country. The vertical part of the permanent magnetism it has acquired in the building will make the bottom part of the hull have polarity of the kind that attracts the north-pointing end of the needle, while the upper works will, of course, have polarity of the opposite kind. What will be the effect on a compass standing on the upper deck or on the bridge when the ship heels? The polarity of the bottom of the hull will then give the north point of the compass a pull to the side that is tilted up. The heeling error due to this cause will be a maximum if the ship's head is north or south; it will be zero if the ship's head is east or west. In a steamer, unless there has been

a displacement of cargo, there is no continued heel to one side, such as you have in a sailing ship when running on a particular tack, but nevertheless it is important to correct the heeling error, for as the ship rolls the effect of heeling error is to give the north point of the compass alternate pulls to port and starboard, which tend to set it swinging.

Hence, in addition to the horizontal magnet bars which act as correctors of the semicircular error, Kelvin put in his binnacle an upright bar or bars also of permanently magnetized steel, the first function of which is to correct the heeling error so far as that is due to the vertical part of the permanent magnetism of the ship. These bars are put directly under the centre of the compass card. They are adjusted by raising or lowering a can which contains them in the middle of the binnacle.

Thus by a combination of three sets of correcting magnets, two horizontal and one vertical, he obtains complete neutralization of the disturbing effect of the ship's permanent magnetism, both as respects semi-circular error in change of the ship's course and heeling error as she heels or rolls. From time to time, if the condition of perfect compensation is to be maintained, the position of these various correctors has to be altered, because of changes which take place in the so-called permanent magnetism of the ship. The navigator has always to be on the look-out for the gradual development of errors from this cause, however perfectly the first adjustment has been carried out.

We have next to consider the effects of induced magnetism. The most important of these arise from the fact that the ship is a long body of magnetizable material turning in a horizontal plane and therefore subject to the inductive influence of the horizontal component of the earth's magnetic field. Think of what would happen

if we were to take a pivoted compass needle, and place it above or below a bar of soft iron, and slowly turn the bar round in a horizontal plane. We are to think of the bar as having no appreciable magnetic hysteresis, so that in every position it is the induced effect only with which we have to do. What will be the nature of the deviation ? When the bar points north, and again when it points south, there is no deflection of the needle, for though the magnetism of the bar is then at its strongest, the field due to it is in line with the undisturbed earth field. Also when the bar points east or west there is no deflection, for the bar then takes up no magnetism. But between these points, namely, when the bar is pointing NE., SE., SW., or NW., the deflection is at its maximum. So in a ship's compass this error, due to the purely transient magnetism induced by the horizontal component of the earth's field, has its maximum on these four courses, once in each quadrant, and for that reason it is called the quadrantal error.

It is due, as we have seen, to the ship's being a long body, extending fore and aft, and it is corrected by balancing this excess of fore and aft iron by other iron, placed quite near the compass and on either side of it. The two balls which you see on the side of the Kelvin binnacle are the correctors for quadrantal error. They are adjusted in the first place by selecting a suitable size of ball, and then placing them nearer to or further from the compass until on swinging the ship the quadrantal error disappears. The possibility of correcting the quadrantal error in this way had been pointed out by Airy as early as 1840 ; but with the old form of compass card and needles it could not be done, because of the excessive length and large magnetic moment of the needles. To apply the method to a compass of the old pattern would have needed globes of impracticable size, not a few inches

in diameter as these are, but weighing tons. Kelvin, with his short needles on a light card, made it possible to carry out the process, and so gave the world for the first time a compass that would point truly to the magnetic north, notwithstanding all the perturbations due to permanent and induced magnetism in the iron of the ship.

One more of the disturbing causes remains to be mentioned. The vertical component of the earth's field induces magnetism as well as the horizontal component, and gives rise to an additional error of two kinds, namely, a further semicircular error and a further heeling error. These are distinct from the semicircular error and heeling error due to permanent magnetism, and the right way to correct them is to fix a bar of soft iron in a vertical position¹ near the binnacle, so that the magnetism induced in it will act as a counterbalance. This is the Flinders bar, so called because its use was pointed out by Captain Flinders as early as 1801. It has generally to be fixed in front of the binnacle, and in Kelvin's compass it is made in several separate lengths of soft iron, which can be put together to make up a bar giving any necessary amount of correcting effect.

The main function of the Flinders bar is to correct the semicircular error due to induced vertical magnetism. So far as the heeling error is concerned it also helps, but in practice it is found convenient to correct a part of the heeling error due to induced magnetism by means of the same kind of permanent magnet correctors as I have already described in speaking of the heeling error due to permanent magnetism, namely, vertical magnet bars placed in a can in the binnacle directly under the centre of the compass card. The number or height of these bars has therefore to be altered from time to time, as

¹ That is to say, vertical when the ship is on even keel, or perpendicular to the deck.

the ship moves to regions where the vertical force is different.

When the heeling error is fully corrected we escape one cause of the unsteadiness which a compass shows when a ship rolls, for we escape the magnetic cause of oscillation, namely, the alternate magnetic pull to port and starboard. But a purely dynamical cause of unsteadiness necessarily remains, arising from the fact that the point of suspension of a compass card must be placed some way from the centre of gravity to hold the card level against the dipping action of the earth's magnetic field. Consequently every roll to either side applies a mechanical couple tending to set up oscillation, and if the period of the roll were the same, or nearly the same, as the period of oscillation of the card, the disturbance would become so great as to make steering by compass impossible. It was to secure steadiness in this sense that Kelvin strove to give his compass card a long period of oscillation, recognizing that the right way to obtain steadiness was to make the period much longer than the period of the slowest rolling motion liable to occur in a ship, at the same time keeping the friction as small as possible. The problem of securing a steady frictionless compass was a problem where, as in the invention of the mirror galvanometer, his genius for practical dynamics guided him to the right solution. In the case of the compass it was rendered difficult by the fact that other conditions, apparently antagonistic, had at the same time to be satisfied in order that the correction of magnetic errors might be completely carried out.

As an adjunct to the improved compass he invented the azimuth mirror, an apparatus which, standing on the top of the bowl, allows the bearings of distant objects to be readily taken by sighting over the tops of the correcting globes. It slides on the top so as to turn in any

direction, and carries an optical device by which the distant object and its bearing on the compass card are simultaneously brought into view.

All this was the work of several years. His first article on Terrestrial magnetism and the mariner's compass appeared in *Good Words* in 1874; it was an introductory historical sketch, and the second article did not appear till 1879. During these five years he had, as he said, been learning his subject. The problem of obtaining a compass which would be steadier at sea, and at the same time better adapted for the perfect correction of the errors due to the iron of the ship, forced itself on him when he tried to write the article. 'When there seemed a possibility,' he said, 'of finding a compass which should fulfil the conditions of the problem, I felt it impossible complacently to describe compasses which perform their duty ill, or less well than might be, through not fulfilling these conditions.' Hence what he had at first thought would be the 'pleasant and easy task' of describing an instrument familiar to navigators for six hundred years took five years to accomplish, and before it was completed he had given to the compass a character of precision it never possessed before.

He also invented the *Deflector*, an instrument for testing the adjustment of the various correcting magnets. By means of the deflector the compass error can be corrected when sights are not available, either of the sun or of marks ashore, to determine the true course in each position as the ship is being swung. The principle on which the deflector works is that when the correcting magnets are rightly set the magnetic field acting on the compass is the same (at any one place) in whatever direction the ship's head points.

It consists of a pair of magnets arranged somewhat like the legs of a pair of compasses. By opening the legs their power to deflect the compass needle is increased. This

instrument is placed on the glass top of the compass bowl, and the legs are opened until some definite large angle of deflection is observed, say 85° . Then it is removed ; the ship's head is turned to another course, and the deflector is replaced. If the same opening of the legs just suffices to give the same deflection on this second course, the directing field on both courses is the same. The process is repeated for other courses, and if differences are found the correcting magnets are adjusted until they disappear.

Lord Kelvin also at a later date designed an instrument for measuring the vertical magnetic force to facilitate the compass adjuster's correction of the heeling error by giving the means of comparing the vertical component of the earth's field on shore with its value at the compass. It was as recently as 1906 that he brought out the latest form of this apparatus.

The evolution of the Kelvin compass, in its main features, took about five years ; but a longer task lay before the inventor in overcoming the professional conservatism of sailors, the objections of the so-called practical man, active hostility in some quarters, and the passive resistance of official inertia. Gradually the compass came to be used in merchant vessels of the best appointed class. Enlightened navigators, such as Captain Lecky, the author of the well-known *Wrinkles in Navigation*, became its enthusiastic advocate. Foreign Admiralties took it up, and in our own service individual officers were quick to see its merits. Captain Fisher, now Admiral of the Fleet Lord Fisher, was warm in its praise, after observing its behaviour in ships under his command, first in the *Northampton* in rough weather and afterwards in the *Inflexible* during the firing of heavy guns in the bombardment of Alexandria. That was in 1882. But it was not until November 1889 that the Superintendent of the Compass Department of the Admiralty was in a position

to inform Lord Kelvin that his 10-inch compass was to be adopted as the standard compass for the Navy. This was twelve years after the date of his patent, and more than eleven years after he had laid the invention formally before the First Lord. The way of the inventor, like that of the transgressor, may still be hard, but I trust it is not so hard now as it was then. One does not care to dwell on the spectacle of a Kelvin spending his strength in disheartening effort as the sea beats against a cliff. It is painful to read the correspondence and discussions of those weary years. One does it with increased admiration of the infinite patience which at last secured to us the benefits of his practical genius.

The use of the Kelvin compass is now very general. In the Navy a modified form, due to Captain Chetwynd, with a card immersed in liquid, is taking the place of the Kelvin dry card in the newer ships, as being steadier still under gun-fire. The system of correction remains substantially unchanged, and the naval compass continues to embody the same mechanical features as formed the basis of Kelvin's invention.

In the Navigational Sounding Machine we have another invention of first-rate importance, second only to the compass in practical value to sailors, and remarkable for its extreme simplicity. It was his cable-laying experience that first led Kelvin to take an interest in deep-sea sounding. The process, as then carried out, was a laborious one. The line was a rope, an inch and a half in circumference, and though it carried a very heavy sinker the resistance to its motion through the water was so great that it took a long time to reach the bottom. For the same reason the ship had to be stopped while the line ran out, and, except in shallow water, while it was being heaved in. Many hands were needed, and much time was spent in making a cast. Hence it came about that

the operation of sounding, beyond the use of the hand-lead in quite shallow water, was but little resorted to as an aid to navigation, notwithstanding the importance of the indications it could give in such cases as when a ship was approaching land in a fog or in circumstances which made the exact position uncertain, when the depth might be anything up to, say, one or two hundred fathoms.

I have spoken already of Thomson's study of the forces acting on a cable during its submersion. Applying these principles to the sounding-line, he recognized that to make the line slip down quickly, it should have the smallest possible and the smoothest possible surface, and this led him to use a single wire of steel—the steel of high tensile strength used in pianofortes. In 1872 he demonstrated the practicability of using wire, by taking a sounding and finding bottom at 2,700 fathoms in the Bay of Biscay, with a 30-lb. sinker and a single wire of No. 22 gauge. He soon devised a suitable drum and winding-in wheel for deep-sea use, and from this was developed later a compact form of navigational sounding machine by which flying soundings are taken without stopping the ship.

In a flying sounding the wire streams out behind, taking an oblique course to the bottom, and the length of wire that runs out is greatly in excess of the depth. To read the depth directly, Thomson invented several forms of depth gauge, the simplest of which is a long narrow glass tube, closed at the top, and coated inside with chromate of silver or some other chemical which is discoloured by the action of sea-water. This tube is put in a protecting case which is attached near the sinker, and as it descends the increased pressure forces the sea-water up into it, compressing the air, and indicating the depth by the height to which the chemical lining is discoloured. Accordingly the depth is read off by laying the tube against a scale when the line is again drawn on board.

The Thomson Sounder has become a standard navigational appliance. The length of wire in common use is three hundred fathoms. A strand of seven fine steel wires, which gives greater flexibility, is now substituted for the single wire. It runs out under a regulated tension, supplied by a rope brake which retards the rotation of the drum on which the wire is wound. When the sinker touches bottom the tension is at once seen to slacken, or rather felt to slacken by a sailor who keeps a little rod of wood lightly pressed against the wire while it runs out ; the drum is stopped, and the wire is slowly wound in again by hand, or in the latest naval type by electric motor. Lord Kelvin's latest improvements in the machine were made only a year or so before his death : they were, in fact, his last serious inventive work. They include a large horizontal dial for reading the number of fathoms of wire out, and with this it is often practicable to tell the depth very closely without resorting to a depth gauge at all. For in the modern machine the action is so uniform that, at any given speed of ship, a definite relation holds between the depth and the length of wire out, and by finding this relation once for all a table can be prepared by which, when the speed is known and the length of wire out is observed, the depth may be at once inferred. This system is now in regular use in the Navy. A pair of the Kelvin machines stand on the bridge ; the wire runs out along a boom at either side and over an ingeniously designed pulley or fair-lead ; whenever soundings are wanted, they can be taken systematically and in quick succession while the ship proceeds at undiminished speed, and the depth is called out for the information of the navigating officer almost as soon as the wire has stopped running out. Alike in the Navy and the merchant service there is no difficulty in making it a matter of routine to keep the sounding machines going incessantly,

when near shore or within, say, a hundred fathoms in thick weather.

Time presses : but I must say a few words about another of Kelvin's services to navigation ; his advocacy of what is now called the *Position Line* in the working out of a navigator's 'sights'. The ordinary 'sight' of the sun or of a star is an observation of the altitude above the horizon at a known instant of Greenwich time. The navigator takes its altitude by his sextant, and at the same instant reads the Greenwich time by his chronometer. What is the information that such a sight furnishes as to the position of the ship ? In the first place, from the observed Greenwich time you know that the sun or star was at that instant vertically over a particular spot on the earth's surface, and in the second place, from the observed altitude you know that the ship was a certain distance from that spot. If the altitude had been 90° the ship would have been just at the spot in question ; and being less than 90° she must be some way off—somewhere, in fact, on a circle from every point of which the altitude would have the observed value. All the sight tells you, then, is that the ship is somewhere on the circumference of a certain circle, and practically you are concerned with a little bit of the circumference—a short arc in the neighbourhood where you know that the ship happens to be. On the chart this little arc of the circle may be represented with sufficient accuracy as a straight line. This line is called the Position Line for the given sight, and once the position line is drawn on the chart you have a complete representation of all that the sight is able to tell : what it tells is simply that the ship is somewhere on that line. To get the actual position an independent second observation is required : it may be the bearing of an object on land, or it may be another observation of the altitude of a heavenly body, and if

you draw the position line for that also the intersection of the two will fix the place of the ship. Both sights may be of the same body—the sun, for instance—taken at different times, and if the ship has been moving in the interval, the first line must be shifted parallel to itself through a distance representing the run of the ship, before the intersection of the two lines is used to fix the position at the time when the second sight is taken.

It is to an American navigator named Sumner that the honour belongs of first pointing out the desirability of drawing, for every sight, the corresponding position line, and of showing how the line might practically be found. But Sumner's method was somewhat tedious, and the advantages of the Sumner line or position line were but little understood. Kelvin realized them, and saw too how the process of drawing the line might be greatly simplified. For this purpose he published his *Tables for Facilitating Sumner's Method at Sea*, which immensely reduced the labour of calculation, and incidentally supplied the navigator, in the working out of the sight, with a piece of information of great value, namely, the true bearing of the sun or star. Its value is this, that by comparing the true bearing with the bearing taken by compass at the same time as the sight, a test of the accuracy of the compass is incidentally obtained.

The particular method of mathematical solution introduced by Kelvin was not much taken up, and since then other ways of drawing the position line have been devised which are generally preferred. But the main point is that navigators have now become familiar with the important gospel which Kelvin insistently preached, that for every sight the line should be independently drawn. The position line has come widely into use. It is accepted as the right means of representing the result of each separate observation. It expresses the truth, the whole truth, and

nothing but the truth, of what each sight tells as to the position of the ship. I believe it is in great part owing to Kelvin that this revolution in the practical art of nautical astronomy has come about.

In this connection I must tell a little story. His *Tables for Facilitating Sumner's Method* on their publication in 1876 were reviewed in *Nature* very favourably, but were subsequently attacked in that journal by the Astronomer Royal, the late Sir George Airy, then an old man. The criticism was based on a misapprehension of the function of the position line, a mistake difficult now to understand. I had helped in getting out the tables, and was indignant at a criticism which might do much harm and was essentially invalid. I telegraphed to Kelvin asking his permission to publish a reply. He promptly telegraphed : 'Yes, by all means answer in your own name, but don't hit too hard. Remember he is four times as old as you.'

We must pass over with the barest mention Kelvin's advocacy of periodic occultations as a means of distinguishing lights at sea, the proposal that fixed lights should be identified by causing each to signal some letter of the Morse alphabet as a group of short and longer periods of darkness. Nor can anything be said of the assistance he twice gave to the Admiralty by serving on committees which had to advise as to the selection of types of battleships and cruisers, first in 1871 after the loss of the *Captain*, and again in 1904-5 when the design of the *Dreadnought* was under consideration. For the time that remains must be used to speak of his work in connection with the tides.

It was at Kelvin's instigation that the British Association formed a Committee in 1867 to investigate tidal phenomena by a method of harmonic analysis introduced by him. Writing to Helmholtz in that year he speaks of having spent many a day on the study of tides on board

the *Great Eastern* when waiting for weather or making passages. Members of the Institution of Electrical Engineers are acquainted with the harmonic analysis of Fourier, by which any periodically recurring quantity can be represented as the sum of a series of terms with frequencies which are multiples of the frequency with which the quantity itself recurs. But in Kelvin's analysis of the tides the constituent terms are selected, not as a simple Fourier series, but with reference to the various physically recurring influences which go to build up the resultant tide. The actual tide is treated as the resultant of a group of tides, each due to a physical cause having a definite period of its own determined by reference to the cause to which each constituent tide is due, in the motions of the moon and sun. Thus there is, in the first place, due to the moon, the lunar semidiurnal tide, the chief of all the constituent tides, whose period is half a mean lunar day. Then there is the solar semidiurnal tide, whose period is half a mean solar day. Then there are also diurnal tides due to the fact that the sun and moon have declination—that is to say, that they are not in the plane of the equator, and there are long period tides due to the changes of declination which both these bodies undergo—a fortnightly lunar declinational tide, and a semi-annual solar declinational tide. Further complications arise from the ellipticity of the moon's orbit round the earth, and of the earth's orbit round the sun. These various causes produce inequalities which may be treated as effects got by compounding tides of nearly equal period, corresponding to the beats in an imperfect harmony. Finally, in a restricted tidal channel there is a distortion in the form of the tidal wave which is dealt with, in the analysis, by introducing the higher harmonic terms of a Fourier series in respect of one or more of the chief constituent tides.

The practical utility of the whole process lies in this, that it enables the behaviour of the tide at any port to be predicted with great exactness. After observations of the tides have been made for a sufficiently long time, either by systematic measurements of the water-level from hour to hour, or by means of a self-recording tide-gauge, the analysis can be applied to calculate the phases and amplitudes of the constituent tides, and once that is done, it becomes possible, as a mere matter of computing, to work out the future tides for the port.

To facilitate this process Kelvin invented in the first place a mechanical analyser, for getting the constants of the constituent tides out of the recorded readings of tide-gauges at the port ; but it has been found in practice better to carry out this part of the work without mechanical aid, namely, by measurement and computation. In the second place he invented a mechanical tide predictor which carries out the subsequent part of the operation, giving a very complete automatic synthesis of the constituent effects, drawing a curve, in fact, which shows for a whole year, or longer, the future behaviour of the sea-level at any port for which the constants of the constituent tides have been determined. This machine is now in regular use, at the National Physical Laboratory, for working out the future tides for Indian ports, and the results of its calculations are published in two annual volumes which give full particulars of the future tides for all the chief ports of the Indian Ocean. Thanks to the kindness of Dr. Glazebrook, I am able to show you one of the curves drawn by it—a curve reeled off in an hour or two, which shows the complete tide at a particular port as predicted for half a year.

To get a sufficiently close agreement between prophecy and fact the machine includes twenty-four constituent terms in this mechanical summation of tidal effects. It

compounds in the movement of its tracing-pen that number of simple harmonic motions by means of wheels geared so that in their relative frequencies of rotation they correspond to the frequency of the various constituent tides, and the motions taken from them are adjusted as to amplitude and phase to suit the known constants of the port for which the prediction is being made. The pen is attached to a wire which passes from a fixed point over a succession of pulleys, each of which is caused to rise and fall with the appropriate simple harmonic motion, and the aggregate effect is to give it a displacement which represents with great exactness in every characteristic the rise and fall which the water will really undergo. It is right to add that in bringing his tide predictor to a practical form, Lord Kelvin had much assistance from Mr. E. Roberts, who was employed as computer by the British Association Committee, and by whom the calculation of the gearing was carried out. The chief features of the machine will be seen in the slides now exhibited.

In attempting this account of the work of Kelvin in Telegraphy and Navigation, I am embarrassed by its volume and its range. The time has proved far too short for a fitting notice of discoveries and inventions so various, so fundamental, so far-reaching in their practical effects. And yet we have dealt only with a very small part of the whole achievement of a man not less remarkable for sustained industry than for outstanding originality—a man incessant in action and in thought—of whom it may be truly said that there is no department of physics on which he has not left an abiding impress.

I have said nothing to-night of the lofty flights of scientific imagination which are, perhaps, his highest title to fame. But I have said enough to show that Kelvin was intensely practical. He was quick to recog-

nize a real need : quick also to see how the need should be met. He found material for invention in the most commonplace appliances, because his mental habit was in everything to seek for the how and the why and to ask himself in what way the thing might be done better. And he had an infinite faculty of taking pains : of adhering to a purpose till he secured its full accomplishment : of going on from improvement to improvement in pursuit of the more perfect result. And with all this he had a courage and hopefulness that no opposition could damp, that never accepted defeat.

We may apply to him the words which he himself used of Cyrus Field : 'He possessed an admirable and unapproachable quality, an attribute of heroes : he never knew when to give in.'

1910

VII

SIR CHARLES PARSONS, O.M.

AN OBITUARY NOTICE FOR THE ROYAL SOCIETY,¹ WITH
SOME ADDITIONS

C HARLES ALGERNON PARSONS, whose genius as inventor and engineer has opened up a new era in the production and application of power, was born at 13 Connaught Place, London, on June 13, 1854. A life notable for its intense and sustained creative activity was closed by his death at sea, after a brief illness, on February 11, 1931. He was the youngest of six sons of William Parsons, third Earl of Rosse, and spent his boyhood at the family seat, Birr Castle, Parsonstown, Ireland. The father was a distinguished astronomer and mechanician, whose great reflecting telescope, designed and mainly made by himself, was for long among the wonders of the astronomical world. Its 6-foot speculum of copper-tin alloy was the culmination of work in the casting and polishing of specula on which Lord Rosse had been engaged from 1827. Erected in the grounds of Birr Castle in 1845, the Rosse telescope had then, and for many years after, no rival. The Earl's services to astronomy were recognized by his election as President of the Royal Society for the period 1848-1854. As early as 1844 he had been President of the British Association, and at later meetings he presided over Section G as well as Section A.

¹ *Proc. Roy. Soc., A*, vol. 131 (1931).

He died in 1867, and his eldest son Laurence, who was born fourteen years before Charles, succeeded to the earldom. Laurence shared his father's tastes and had been an active collaborator in the astronomical work. A memoir by him on the great nebula in Orion was published in the *Philosophical Transactions* of that year; and another, on radiation from the moon, formed the Bakerian Lecture of 1873.

Of the other sons, the second and third died in early boyhood. The fourth, Randal—now the only survivor—was for many years Rector of Sandhurst and is an Honorary Canon of Christ Church. In the fifth son, Richard Clere, who was three years senior to Charles, the family talent took a somewhat different course. He had a successful career as a civil engineer and died in 1923, after carrying out many schemes of water supply and drainage, especially in the cities of South America.

'We never attended any school,' writes Canon Parsons. 'Everything was provided at home to develop natural ability and mechanical taste, which my brothers, not myself, possessed to a great degree. They had workshops, foundries—iron and brass—for everything was made at the Castle—and my father was always with them. He was a first-class mechanician and could do almost everything with his hands. My brothers were practical engineers before they reached the age for leaving home or attending college, and the theoretical part of their training was imparted by the tutors who, in succession, lived with the family and were our greatest friends personally. Charles showed a strong practical taste for mechanics very early. He was perfectly happy if only cardboard, hat-pins, sealing-wax could be obtained, and one of his child-delights was to make cardboard clocks. These were in time discarded for mechanical toys, home made. I remember one day his running in to my mother with a splinter of steel hanging in the white of an eye

from the lock of an air-gun he had made himself. She had the courage to draw it out and no harm was done. Another time he had the whole of his eyebrows taken off by an explosion of gunpowder.'

The family motto was never 'safety first'.

One gathers that in this remarkable education the mother had no unimportant share. She was Mary Field, daughter of a Yorkshire squire, who married the astronomer in 1836 and kept up a lively sympathy in his pursuits. Her own aptitude for handicraft made her a delightful companion to mechanically-minded sons. After describing the workshops, forge, foundry, and chemical laboratory which the third Earl established in the moat and keep of the old Castle, Canon Parsons remarks, 'My mother was deeply interested in these works and took her part. She was skilled in modelling in wax and made all the moulds for the ornamental work of the large bronze gates at the entrance of the front hall of the Castle. . . . When photography was invented, she had a photographic room fitted up adjoining the workroom and spent much time there.'

The third Earl's death left her in sole charge of the three younger sons; Charles, the youngest, was then thirteen. The process of education at home went on until it was time for each boy in turn to go to the University. 'She made a home for us boys after my father's death, at first at Birr, then at Dublin, and afterwards in London, until her death. The family life continued even after Charles went to Cambridge, and the vacations were spent together. . . . She was the best of mothers; her influence affected all our lives. She was highly intellectual and simply gave herself for her children.'

The family habit, so long as the father lived, was to spend most of the summer in a spacious yacht, the *Titania*. The boys' tutor was always of the party; they

had regular hours of study which were strictly kept. Thus Charles learnt not a little of seamanship and navigation before entering his teens.

After their father's death, Randal, Clere, and Charles went with their mother each year for a tour in Switzerland, North Italy, or the Tyrol. When Charles proceeded to Cambridge in 1873, his mother left Dublin and settled in London for the rest of her life. She died in 1885, having survived long enough to see Charles produce his first steam turbine.

The tutors were mathematicians to whom the great telescope offered a special inducement to join the Earl's household. Among them, in the double capacity of astronomer and tutor, was Sir Robert Ball, whose published Reminiscences tell of service at Birr from 1865 to 1867. He claims 'the great honour of instilling the elements of algebra and Euclid into the famous inventor who has revolutionized the use of steam. . . . It would seem that he inherited his father's brilliant mechanical genius, with an enormous increase in its effect on the world.' He describes Charles as constantly resorting to a little workshop where he made all sorts of machines, among them a sounding gauge which measured the depth of water by registering the pressure of air confined in a glass tube, much as Kelvin did some years later in a well-known device.

Another exploit on the part of Charles and Clere was to build, with much toil, a steam road-carriage. This was long before any form of motor vehicle had come to challenge the supremacy of the horse. On a flat base, like that of a lorry, with four wheels, the front pair of which could be steered, they mounted a boiler and a vertical engine which drove the after pair through a cardan shaft, giving the carriage a speed of some seven miles an hour. There was a cross bench to carry pas-

sengers. The experiment came to a tragic end. One day in 1869 when Clere was driving, Charles stoking, and Randal running behind, they had a cousin of the family, Lady Bangor, seated with her husband on the bench. She made a sudden movement, overbalanced, and, falling on the road, was instantly killed.

Enough has been said to show how heredity and environment combined to make Charles Parsons a scientific engineer. From his father and probably from both parents he inherited qualities which were fostered by every part of his training. His nursery was a workshop, his toys were tools, or the things he could himself use tools to create. Nature and acquired habit alike led him, in maturity as in childhood, to think unconventionally, to seek the solution of problems in ways that had not been attempted before. With Parsons life was a sort of hurdle race : a difficulty was simply a thing to be overcome. An obstacle was never a bar ; it was a challenge, an incentive to effort. He revelled in accomplishing what to most men seemed impossible. Untiring, amazingly fertile of ideas, infinitely patient when he had to deal only with the caprices of inanimate things, he found no finality in failure. It meant no more than that another scheme should be tried. His schemes were always carefully planned. He passed from experiment to experiment, assiduous, undiscouraged, until at length he could admit success. But in measuring success he was his own severest critic. A machine of his devising might seem to function very well ; his concern, however, was always with the defects and the possibilities of improvement. At every stage in his long development of an invention the better was the enemy of the good. This attitude towards his own work must often have distressed his colleagues—he would find reasons for scrapping what they thought ready for the market. But, looking back

now, we see that his passion for improving what was already good was in truth the secret of his finest achievements.

Parsons used in after life to say that he had missed much through not being sent to school. He did, undoubtedly, miss something. Shy, self-contained, inexpressive, he never wholly shook off certain characteristics which a public school might have masked or cured. To the last, even in the universal celebrity of his riper years, he kept an air of self-effacement, an exaggerated though wholly natural modesty which puzzled strangers as much as it endeared him to his friends. Could this seemingly casual person with the passive hand-shake, the hesitating fragmentary utterance, be the world-famous inventor, the dreamer who compelled his dreams to come true, the man of indomitable will who removed mountains by works no less than by faith? In the early stages of his career it must have been a handicap to appear at first sight so curiously ineffective, to belie so completely the force which a closer acquaintance gradually discovered.

But if a public school had run him into a common mould, would the gain have been worth the cost? He might have been easier with men who did not wish him to have his own way—a more acquiescent colleague, less sensitive to criticism, less impatient of interference, more tolerant and less exacting. But there would have been grave loss had he thus become standardized, had his uncompromising individualism been shaken, had he been schooled into accepting the guidance of other minds. He was not made to be a member of a team. It was better for the world that he should have his head and be allowed to go his own way. That way was not always easy to understand, and he had little ability—perhaps little wish—to explain it. But men came to see what the goal was when, as generally happened, they found it had been reached.

What is standard bread for the average boy may be pernicious fare for the budding genius. To Parsons, in any case, school would have been at best a poor substitute for the surroundings in which he spent his boyhood. It is safe to say that the actual home training, both of brain and hand, was ideal for the work he was afterwards to do.

The family tradition was that the boys should go on to Trinity College, Dublin, where their father had been Chancellor, and thither Charles went in 1872. After reading mathematics in Dublin for a year, he entered St. John's College, Cambridge, where he became a pupil of Routh, the famous mathematical coach. In 1877 he passed out as eleventh wrangler—a place which his College friends did not think a proper measure of his powers. Sir Donald MacAlister, who was senior wrangler of that year, says that Parsons beat him in 'problems' but was comparatively weak in 'bookwork'. There was no Engineering School in the Cambridge of those days, but the table in Parsons' room, with its litter of models, bore witness to his continued interest in matters which the tripos did not touch. He was scheming then a quickly rotative epicycloidal engine to which he gave practical form during the apprenticeship which followed his college course. His contemporaries describe him as very quiet and shy, liked for his modesty, sociable and even convivial on occasion. The shyness which they all remarked was broken down by the intimacies of the Lady Margaret Boat Club, where, being very strong, he pulled an effective oar. His last appearance on the river was in the May races of 1877, when he took part in a Homeric struggle, the Iliad of which still lives in college story. The Lady Margaret boat bumped First Trinity; but their bows were smashed in and the boat sunk. A quick repair was completed by working on it all night, and

next evening they bumped Third Trinity. Canon Prior writes :

' I well recollect his great long back on which it was my job to keep my eye fixed. He was 3 and I was bow, and I also recollect how when we were all in the water together he got me out of the muddle of oars and wreckage and helped me to the bank. He was enormously delighted that we had bumped Trinity.'

The reserve of the shyest undergraduate could not be proof against such events. Parsons was jubilant, and college tradition tells that after the bump-supper he was with difficulty disentangled from a lamp-post to which he clung with the tenacity that afterwards proved to be one of his most valuable characteristics. More than forty years later those glorious memories were revived. In 1920 Parsons collected as many of the boat's crew as could be found to meet at dinner one of their number who was then High Commissioner for New Zealand. So far as is known, the tempered joviality of that evening had no lamp-post sequel : one imagines the elderly gentlemen content to disperse tamely, perhaps after singing ' Forty Years on '.

It was curious to notice, in Parsons' professional life, how little direct use he made of mathematical calculation. Algebra was a tool for which he did not seem to care. While his assistants were busy with their pencils working out a stated problem, he would find a result by some mental process which he made no attempt to formulate, but in which he appeared to trust more than in symbols. None the less, the intellectual discipline of the Cambridge days had left its mark. It had given him a sound working knowledge of dynamics which experience converted into something like an instinct. It had bred a definite, if non-formal, mathematical habit of mind in which the prin-

ciples of physics and mechanics were the only accepted guide in interpreting experience and controlling design. Its influence could be traced in the precision and order of his written statements, in the clearness of his prognosis when he was about to make an experiment, in the selection of methods and the analysis of results. With Parsons experiment was never haphazard ; it was planned to clear up some dark spot, and it was turned on that with the concentration of one of his own searchlights.

At the end of his Cambridge course he went to Elswick as a pupil-apprentice in the Armstrong works. There he spent three or four years, improving his skill in handicraft, learning the ways of workmen, and seeing how an establishment was run in which engineering output proceeded on a grand scale under conditions where design and production had to take account of cost. His mind was in a ferment of invention and he was allowed to bring some of his ideas to the test. A contemporary remarks that he made a name for being the most industrious apprentice the Elswick works had ever known. While still a pupil there Parsons put into working form the epicycloidal engine he had devised and modelled in his college rooms. Its object was to produce rotary motion at a high speed with but little action of reciprocating parts. In this it might be called a precursor of the steam turbine, where the object was completely attained of getting very high speed with no reciprocation at all. He also began experiments on driving torpedoes by means of rockets. By the time he left Elswick his brother Clere had joined the firm of Messrs. Kitson at the Airedale Foundry in Leeds, and for about two years Charles, under an agreement with the firm, continued the manufacture of his engine there along with much experimental work. The torpedo trials went on, permission being given to carry them out in Roundhay Lake. They

had fair success ; speeds up to 20 knots were reached ; but the rockets were found to be uncertain and unsafe.

Writing many years afterwards of the incidents of that period (1884) Parsons says :

' I was married and wanted to settle down and start business in earnest, and there was a good opening with Clarke, Chapman & Co., of Gateshead, as junior partner. At Gateshead it was at first contemplated to go on with the rocket experiments, but Messrs. Clarke, Chapman being much interested in electric light and having decided on an electrical department, including the manufacture of incandescent lamps, I put aside the rocket experiments, and steam turbine experiments were started, as the turbine appeared very suitable for the electric lighting of ships.'

On April 23, 1884, he took out his first patent for the steam turbine, or rather two patents of the same date (Nos. 6734 and 6735). From these it is clear that the primary motive was to find a means of giving very rapid rotation to the armature of a dynamo. No. 6734 begins thus :

' My invention is designed to produce an electrical generator which may be driven at a very high rate of speed, several or many times as fast as such machines are now driven, the object being to obtain a large current or a high electromotive force, or both, from a small machine, and also to obtain an increased efficiency.'

The specification goes on to describe the dynamo in detail, and claims, among other things, the driving of it by the turbine which, in its more general aspect, forms the subject matter of Patent No. 6735. The dynamo, he used to say, gave him quite as much trouble as the turbine. In those days dynamo design was largely a matter of trial and error ; it was not till 1886 that John and Edward Hopkinson formulated the principle of the

magnetic circuit. For Parsons the problem was complicated by the enormous centrifugal forces which the armature had to bear.

During the partnership with Clarke, Chapman & Co., which lasted from 1884 to 1889, the manufacture of the combined steam turbine and dynamo was developed mainly for the electric lighting of ships, but only on a small scale. An early model was shown at the Inventions Exhibition in 1885, where it attracted much attention as a new departure in the use of steam for motive power. Parsons was dissatisfied with what seemed meagre progress. He wished to embark on costly experiments, having a faith in the future of the turbine which nobody was disposed to share. His temperament made any partnership irksome. It is not surprising that, after five years, this one was dissolved. With the financial help of a few friends he then set up works of his own at Heaton in Newcastle-upon-Tyne for the manufacture of turbines and dynamos. It was an ambitious venture ; the works were by no means small, and his zeal for experiment added to the risk. There were years of waiting for a dividend ; some lost heart, himself never. In the end his own faith and his friends' faith found ample reward.

A curious tangle added to the difficulty of that trying time. By the deed of partnership with Clarke, Chapman & Co., all patents taken out by any partner became the property of the firm. The value of Parsons' patents was still highly problematical at the date when the partnership was dissolved. To settle the question—not an easy one—of what Parsons should pay for the right to hold them, recourse was had to arbitration ; but before it was completed an agreement was come to under which the patents were left in his late partners' hands. This arrangement lasted for about five years, and although

Parsons continued to develop the turbine during that period, he could do so only with modifications which were designed to keep it outside of the lines specified in his own early patents. The restriction thus imposed was a serious impediment, nevertheless he made notable advances which went far to establish the reputation of the turbine and to pave the way for its ultimate success.

In 1894 he recovered possession of the early patents and was free to return to the original lines of his invention, which were, on the whole, definitely better. In his first turbine the general direction of flow of the steam had been parallel to the axis. In the modified form, to which he was for some years limited, he made the flow radial. On recovering the patents he reverted to axial flow, and this feature is retained in nearly all modern turbines. Later the term of validity of the fundamental turbine patent was extended for six years, in recognition of the great value of the invention and the smallness of the reward it had at that time received.

To understand the genesis of Parsons' early inventions, it may be useful to recall the trend of applied science in the eighteen-eighties when his work began. It was a time of exceptional stir and change. The engineering world was teeming with untried notions. Explorers were busy in a country of whose landmarks they knew next to nothing. From being little more than the servant of the telegraph, electricity suddenly became a big part of engineering. It was an agent with unlimited possibilities. Clearly it might serve for distributing light and power, but how that was to be done involved many questions which were still to be settled. To manufacture electricity was the initial problem; to apply it to novel uses offered a vista of further problems which inventors were eager to attack. The magneto-electric generator had led up to the invention of the self-exciting dynamo;

small dynamos of the types introduced by Gramme and by Siemens were already serving to illuminate open spaces by means of arc lamps. In 1879 and 1880 Edison and Swan were separately at work on the incandescent filament, and nervous holders of gas stock were being assured by their chairmen that there was nothing to fear from the electric light. At the end of 1881 Sir William Thomson's lighting of his house by Swan lamps was a notable event. Such an installation was isolated and experimental; as yet there was nowhere in Britain a public electric supply. A year later, and we read of 'almost daily' flotations of supply companies and find a hot controversy going on over the terms of an Electric Lighting Bill which was hastily promoted to safeguard the interests of local authorities.

Into this welter came Parsons, realizing that an urgent mechanical need of the moment was an engine that might be directly coupled to the armature of a dynamo, producing the high speed of rotation which that required.

For such a purpose reciprocating motion was out of place. The motion of the armature was purely rotary: the motion of the engine should be purely rotary too. Moreover, the speed of the armature must be high and might with advantage be very high. Parsons, as his first patent shows, realized the special merit for this purpose of a speed much greater than any to which engine builders were accustomed, even when they increased it by using a belt and pulley between engine and dynamo. Rapid driving of a dynamo armature was his primary concern.

From ancient times it had been known that rotative motion could be obtained by the direct action of steam. Steam windmills, or what may be called steam turbines, had been philosophical toys long before the days of Newcomen and Watt. The essence of a steam turbine is that

in exerting pressure the steam, instead of pushing a piston, pushes some of the steam itself through an orifice or nozzle, setting up a jet which may play on the vanes of a revolving wheel, or may cause the jet-pipe itself to move backwards by reaction from the issuing steam. Such toys were described by Hero of Alexandria in a treatise on pneumatics which dates from the second century before Christ. Hero's *Æolipile*, though it was no more than a toy, may claim to be the earliest steam engine of which we have any record: it is in fact a reaction turbine of the simplest possible kind. An equally simple impulse turbine is described by Giovanni Branca in a curious volume entitled *Le Machine*, which was printed in Rome in 1629. Branca illustrates many devices which were clearly fruits of imagination rather than experiment. It is safe to say that the impulse turbine as he illustrates it, driving a set of ore-crushers through a train of mechanism, is a suggestion that was never realized. If it had been tried, it would not have worked.

Many subsequent inventors took up the notion of a steam turbine, but none of them succeeded in giving it practical shape until the problem was attacked by Parsons. The machine described in his patent of April 1884 embodied a feature to which the triumph of Parsons' turbine is mainly due. That is the division of the steam's action into a large number of successive stages. In earlier turbines, whether working by impulse or reaction, the fundamental difficulty had been that a jet of steam escaping under pressure acquired a very high velocity, and thus needed an excessively rapid movement of the vanes or the nozzles if they were to take up any respectable fraction of the energy of the jet. Parsons saw that the right way of overcoming this was to divide the whole drop of pressure into a series of little steps, with the

result that in each step the steam acquires only a moderate velocity, and it is practicable to make the vanes move fast enough to take up nearly all the energy. This is true of each stage in succession : the steam passes from stage to stage, alternately, acquiring motion and giving it up to moving vanes, until at last it escapes. The vanes are arranged in a series of revolving rings. When the steam has passed through the last ring its work is done ; it has expanded down to the lowest available pressure. The effective work of the machine is an aggregate of the work done by the steam on the successive rings, through which it has expanded step by step. The Parsons Turbine is called 'compound' because it divides the whole expansion into a number of separate steps.

On these lines he built, in 1884, his first compound steam turbine which is now preserved in the Science Museum at South Kensington. Steam flowed through a long annulus between a rapidly revolving shaft or drum and a fixed outer casing in the form of a larger cylinder. On its way the steam passed through a series of many turbines arranged as rings in the annular space. Each of these turbines consisted of a ring of fixed guide-blades projecting inwards from the casing, and a ring of moving blades projecting outwards from the drum and turning with it. Thus the whole annular space between drum and casing was occupied by a series of alternate rings of fixed blades and moving blades, placed near together, with no more clearance over the tips than was needed to escape contact. In each ring the blades were set obliquely ; the fixed ones formed, as it were, a ring of nozzles, and delivered jets of steam against the next ring of blades, which served as moving vanes. But the action on these was not one of pure impulse, for in streaming through the passages between the moving blades the steam acquired a new relative velocity ; hence the

force which it exerted on these blades was due partly to reaction. The fixed and moving blades of a Parsons turbine are in fact exactly alike, which gives the whole construction a remarkable simplicity. In the earliest turbine the steam entered at the middle of the length and flowed both ways towards the ends, thereby causing no end thrust ; but in most designs the steam enters at one end only and a lengthwise balance is obtained in other ways. The blades are made longer as the exhaust end is approached, in order to provide a bigger passage for the expanded steam.

Nothing, in a sense, could be simpler than this compound steam windmill with the whole series of fixed and moving blades co-operating to make the shaft revolve at a prodigious velocity when the blast of steam was turned on. But to secure that it would run smoothly and without excessive waste of steam was no simple matter. Notwithstanding the division of the whole pressure-drop into many stages the blade-speed had still to be high. In the first turbine, which drove a shunt-wound dynamo and developed about 10 horse-power, the shaft made 18,000 revolutions per minute, giving the blade tips a velocity of about 300 feet per second. The dynamical problem of so constructing and supporting the shaft and armature that they could spin without shake at such a pace required much inventive design.

And later, when steam turbines grew and their uses multiplied, every stage in the development made further demands on the inventor's ingenuity and courage and resource. There were many technical advances to be made and much prejudice to be overcome before Parsons convinced other engineers and industrial experts that in this new type of prime-mover they had a convenient, unfailing, and highly economical apparatus for producing power, capable of operating on a scale and with a con-

centration never before approached. Throughout the whole evolution of the steam turbine he continued to be the active and incessant *deus ex machina*. Other inventors appeared and made their contributions, which led in some cases to more or less different designs. But they would be the first to acknowledge that it is to Parsons, far more than to any other man, that credit is due not only for the first conception and the initial experiments, but for the subsequent improvements which have produced the gigantic turbines of to-day and have made them the chief means of generating central-station power and of propelling the biggest ships. All large modern turbines adopt his fundamental plan of multi-compound action by dividing the whole drop of pressure into many successive stages.

Only a few salient points in the history of the steam turbine can be noticed here. For a few years the turbine was made only in small sizes, and its main application was in the electric lighting of ships. It was compact and effective, but it could not be called efficient : critics even called it a notorious steam-eater. In all the early models there was no provision for condensing the steam ; it expanded down to atmospheric pressure and was then discharged. But Parsons was not long in seeing that the addition of a condenser would do even more for the steam turbine than it had done for the reciprocating engine of Watt. For in the turbine it would be easy to continue the expansion down to the most complete vacuum that a condenser could maintain, by merely extending the system of rings of fixed and moving blades so that the steam should do work all the way while its pressure continued to fall and its volume to increase. The increase of volume requires, of course, that the blade-passages must become progressively larger—so the blades are made longer as the condenser is approached,

and in some cases duplex channels are provided in the final stages. The continued expansion of the steam is in fact far more easily carried out in a turbine than in a piston engine, for there it would require enormous pistons and cylinders which, apart from the drawback of their size, would involve much wasteful friction. With the turbine there is a complete escape from such friction, and though the blades have to be made much larger in the rings near the condenser, there is no excessive bulk such as equivalent expansion under a piston would involve. Consequently, the turbine allows, far more completely than the piston engine ever did, the whole potency of the expanding steam to be utilized ; and it thereby becomes, in its modern forms, a far more efficient instrument for the conversion of heat into work. The application of the condenser to the steam turbine marks an epoch : the turbine then entered on what may be called, with no exaggeration, a career of conquest.

By chance it fell to me to make the earliest independent tests of a condensing turbine. In 1891, when Parsons had established his works at Newcastle, a scheme was under discussion for setting up an electric supply station in Cambridge. Somebody made the suggestion that it should be equipped with Parsons' turbines. The turbine was a novel and little-tried appliance about which there was much scepticism. A member of the Cambridge Corporation, who shared this scepticism, asked me to report on it, much as Balaam was asked to report on the Children of Israel. Parsons gave me every facility to make exhaustive trials ; they convinced me that the turbine was the engine of the future, and, like Balaam, I came back blessing where I had been expected to condemn. The addition of a condenser had converted the 'steam-eater' into a prime-mover capable even then of rivalling the performance of an ordinary engine, and

destined later, with further improvements, greatly to surpass it.¹

That was the first of several such occasions. A few months later Parsons had me come again to test the effect of certain changes, one of which was the use of super-heated steam. From time to time a new development gave opportunity for further trials. It was no small privilege to come in contact with the working of so exceptional a mind and to note some of the milestones in his astonishing career. The friendship thus begun continued without a break or cloud. If to some people Parsons seemed difficult, it is right to say that many others—I for one—found him wholly delightful.

One of the occasions of tests was when a turbine, bigger and more efficient than any turned out before, had been built to the order of the city of Elberfeld, and a group of distinguished German engineers came over to conduct the official trials which Parsons commissioned me to witness. The trials began badly, for in a preliminary run there was some rather serious stripping of the turbine blades. But Parsons met the emergency with his usual resource, and the visitors had an opportunity of seeing how quickly the defect could be repaired. After that all went well, and as the testing proceeded to a more than satisfactory finish it was amusing to observe the scarcely repressed astonishment that an invention so admirable should spring from a non-German source.

Another occasion was in 1897 when Parsons had fitted up his little experimental vessel, the *Turbinia*, to investigate the suitability of the turbine for driving ships. This famous craft, 100 feet long and of 9 feet beam, was

¹ The turbine then tested, which was the first to be fitted with a condenser, was of the radial-flow type. It was installed at the Cambridge Electric Supply Station in 1892, and, after many years' service there, it is also now preserved in the Science Museum at South Kensington.

built at Wallsend in 1894. She was originally fitted with a single propeller shaft driven by a radial-flow turbine. The results were disappointing on account of the phenomenon of cavitation, to which fuller reference will be made below. Many different propellers were tried, but their action was unsatisfactory until, in 1896, Parsons substituted a three-shaft arrangement in which each shaft was driven by an axial-flow turbine. The turbines, which developed more than 2,000 horse-power, formed a compound series; steam passed through all three in succession, their dimensions being adapted for high, intermediate, and low pressures respectively. Further experiments were then made with various forms of propeller. These changes led to a great improvement in the propulsive efficiency, and in April 1897 trials were carried out which convincingly demonstrated the success of Parsons' long and persistent efforts.¹ After we had been cruising for several days at various speeds over a measured mile on the north-east coast, observing the relation of steam consumption to speed in weather which was too rough to allow the engines to be worked at their full power, we were returning up the Tyne at the modest pace allowed by local regulations. The river, as it happened, was nearly clear of other craft, the tide slack and the water smooth. Passing the posts of a measured mile on the river bank below Wallsend, Parsons was tempted and said, 'What about a full-power run here?' to which I replied, 'She's your ship.' In a few minutes we were tearing through the water at a speed which, in those days, was a record for any vessel, thereby

¹ Part of the hull of the *Turbinia*, including the engines of 1897, is now in the Science Museum, and near it is the original engine of 1894. An historical account of the early application of the steam turbine to marine propulsion, written by Parsons in 1903, will be found in *Trans. Inst. Nav. Architects*, vol. 45, p. 284; it contains as an appendix a copy of my report describing the *Turbinia* trials of 1897.

completing the series of tests by determining the steam consumption for the highest speed. We ran over the mile three times, with engines full out, and went home very happy. A little later Parsons took the *Turbinia* round to the Solent, where she amazed the Fleet at the Diamond Jubilee Review. He had a permit to run between the lines, but the midshipmen whose duty it was to keep the course did not know this, and were outraged to have an intruder disregard their excited protests and—what was worse—utterly outpace their patrol boats.

A lady who was there, Miss Rosaline Masson, has sent me her recollections of that dramatic moment :

' I was yachting with friends in English waters in the summer of 1897 and was present in the Solent at the great Naval Review of the Diamond Jubilee ; and I remember so well, just as the shabby old Royal Yacht *Victoria and Albert* with the Queen on board her, respectfully followed by two huge vessels containing the Lords and Commons, passed slowly through the avenue of warships—the sudden appearance of a little object, low down on the water-line, darting and flashing and foaming about like a mad Puck, up and down and across the long avenues of ships ; and how every one crowded on deck exclaiming " What is it ? " —for it went faster than anything we had ever seen on the face of the waters—and at last it crossed the bows of the Royal Yacht itself with all the water-police boats after it, helplessly in the rear.'

Lord Rayleigh tells some stories of Parsons' handiness. In the early days of motoring he had a small car which was too lightly built and was apt to give trouble. One day he was on the Northumberland moors, far from anywhere, when a shaft got so badly bent in bumping on a rough track that the car would not go. Parsons took it to pieces, lighted a fire to serve as forge, and with stones for hammer and anvil straightened the damaged part,

put all together again, and went his way. That was motoring as he understood and enjoyed it.

Another time, when the operation of fixing the blades in a turbine was a rather novel job, a dispute arose as to how it should be treated in the reckoning of piece-work. At the dinner hour Parsons and one of his staff went in, locked the door, and took off their coats. When the men came back they admitted they must revise their notions of the amount of blading that would constitute a fair day's work. His men had unbounded respect for a chief who not only had the obvious qualities of master, but could say, 'I have served my time as well as you,' and could show, as he did, that the time served in the 'shops' had not been misspent, and had given him a skill in craftsmanship comparable with their own.

In early experiments with the *Turbinia* a problem presented itself which gave Parsons much trouble. It was already known that a screw-propeller, if turning too fast, might waste its effort by creating vacuous spaces in the water which afterwards collapsed. The phenomenon had been noticed a few years before by Sir John Thornycroft and Mr. Barnaby and had been called by them 'cavitation'. When Parsons began marine propulsion he found that this imposed a sharp limit on the permissible rate of revolution. The speed had to be a compromise; a high speed was to the advantage of the turbine; on the other hand, if too high it would lead to much cavitation. Accordingly he made a careful study of the conditions under which cavitation would occur, using for the purpose an experimental tank with glass sides where he could observe the action of the screw-blades under momentary illumination and note the effects of varying their speed, pitch, diameter, and blade-surface. By the help of such experiments he was able to design turbines and propellers, directly coupled, which

could serve effectively for all kinds of fast ships, however large. It was on these lines that turbine propulsion came quickly into favour.

The Admiralty, after trying turbines in destroyers and the cruiser *Amethyst*, were so well satisfied that they were adopted in the *Dreadnought* (1905) and in all new ships. Before long other navies were following the British lead. In the merchant service the first turbine-driven vessel was the Clyde steamer *King Edward* (1901), which was found to consume 15 per cent. less coal than a sister ship with triple-expansion engines. This was followed by the *Queen* and other cross-Channel packets, and soon by several Atlantic liners. The advantages were so conspicuous that in 1904, when plans were under discussion for building the two great Cunarders *Lusitania* and *Mauretania*, then unprecedented in size and power, it was recommended by a committee of experts that turbines should be employed. The decision was a bold one, remarkable as evidence of the faith already felt in Parsons' ability to adapt his invention to untried conditions. It was amply justified by the event. Turbines developing 70,000 shaft horse-power were provided for each ship, and were entirely successful. The turbine had established its position as the normal means of propelling the largest ships both in the Navy and the Mercantile Marine.

Up to that time, and for some years after, the practice was to couple the turbine directly to the propeller shaft. Parsons, however, was dissatisfied with the compromise of speeds which this entailed. He saw that to secure the best effect the turbine should run fast and the propeller slow. This meant that some form of gearing should be put between them. Moreover, so long as direct coupling was retained, the turbine was suitable only for high-speed ships ; with gearing it could be applied as well to

cargo boats and slow craft generally. From the first he had contemplated gearing as a possible feature; his earliest patent for marine propulsion (No. 394 of 1894) contains the following comprehensive claim:

'(1) Propelling a steam vessel by means of a steam turbine, which turbine actuates the propeller or paddle shaft directly or through gearing.'

He decided to try a simple mechanical gear, by putting a small pinion on the turbine shaft which should drive a large wheel on the propeller shaft, through cut teeth of helical form. Accordingly in 1909 the Parsons Marine Steam Turbine Company (a concern which had been formed to take over the marine side of the business) bought an old cargo steamer, the *Vespasian*, the engines of which were of the triple-expansion type. These were taken out and a turbine was substituted with a reducing gear which let the turbine shaft run nearly twenty times as fast as the propeller shaft. The gear worked smoothly; it was found that the loss of power in transmission was almost negligible; and the consumption of fuel was much less than with the old engines. This experiment marks another epoch. Before long it led to the complete abandonment of direct driving in marine turbines and to the universal use of some form of reducing gear, even in the fastest ships. In some instances double-reduction gear, with an intermediate shaft, has been used, but as a rule there is only one step down.

To transmit many thousands of horse-power through the teeth of gear wheels was a new problem. Parsons solved it successfully by his devices for cutting the teeth with extreme accuracy, and by suitable selection and heat-treatment of the steel in which the teeth are cut. Occasionally an electrical transmission of power from the turbine to the propeller shaft is resorted to, but the simple

mechanical connection by toothed wheels is much more usual both in naval and mercantile practice. A large-scale example is to be found in the battle-cruiser *Hood*, where 144,000 horse-power is transmitted to the propellers through single-reduction gearing. In a fast new Cunarder of some 75,000 tons, the building of which is in progress (1931), it is understood that the engines will be single-geared Parsons turbines developing about 175,000 horse-power.

Concurrently with its adoption as a marine engine the steam turbine has become the chief means of generating electricity in countries which depend for power upon the use of fuel. For this purpose, apart from its high efficiency as a converter of heat into mechanical effect, there is a marked advantage in a prime-mover which gives very fast rotary motion, with no vibration, and can be built in compact units each with an immense concentration of power. The requirements of great electric stations are met by turbo-alternators, often developing 50,000 kilowatts or more. In these machines the turbine gives rapid rotation to a two-pole or four-pole field-magnet and thereby generates alternating currents in the coils of the surrounding stator, which are insulated to stand a high potential and are kept cool by a forced circulation of air. The speed is commonly either 3,000 or 1,500 turns per minute, to suit the now usual frequency of 50 cycles per second. Alternators of this type were built by Parsons as early as 1905, generating current at 11,000 volts. In a paper written shortly before his death, he describes one designed to generate 25,000 kilowatts at 33,000 volts, this exceptionally high potential being made possible by a novel method of winding the stator coils. In the whole development of the modern alternator Parsons took from the first a prominent part.

Another of his services has been to advocate high steam-pressure and high superheat, and to design his turbines for such conditions. His influence did much to promote these features of present-day practice. He urged their importance at the first World Power Conference in London in 1924, and again at the second Conference in Berlin in 1930. He gave an effective demonstration of them in the Clyde river steamer *King George V.*, which was placed on service in 1926, and this has led to their application in various large ships. He had already supplied to a power station in Chicago a turbo-alternator of 50,000 kilowatts in which the steam-pressure was 600 lb. per square inch and the temperature 750° F., but to apply similar conditions on board ship was a new departure. These examples will sufficiently indicate how Parsons kept his position to the last as an active leader in steam engineering.

The steam turbine, like any other heat engine, has its efficiency determined by the range of temperature through which the working substance is carried in its cycle of operations, and by the degree to which its action conforms to the ideal cycle of Carnot. From the thermodynamic point of view, Parsons' work may be summarized by saying that he brought the actual steam cycle nearer to the cycle of Carnot, and also that he enlarged the effective range of temperature both by raising the limit at which heat is received and by lowering the limit at which heat is rejected. The steam turbine made these changes practicable. It raised the limit of reception by facilitating the use of high pressure and high superheat. At the other end, it let the steam expand usefully all the way down to the pressure of the condenser ; and, in addition, one of Parsons' subsidiary inventions—the 'vacuum augmenter'—reduced the temperature of condensation nearly to that of the condensing water. The

turbine brings the action of the working substance closer to the Carnot ideal in several respects ; it avoids the alternate give and take of heat between steam and metal which is a cause of loss in all reciprocating steam engines ; it also allows regenerative feed-heating to be adopted, by which the condensed water has its temperature gradually raised before it is returned to the boiler. The general effect of Parsons' inventions has been to double, and more than double, the efficiency with which heat is converted into other forms of energy through the agency of steam.

In his later life Parsons gave much attention to work of another type. For many years he had carried on at Heaton a manufacture of parabolic reflectors for search-lights—an offspring, one may say, of his father's interest in specula. The searchlight mirrors were made from selected plate glass which was softened and formed over moulds of suitable shape ; then carefully annealed to prepare them for the subsequent process of grinding and polishing which was carried out on a special machine devised by Parsons to preserve the parabolic form of the mirror. Finally, the back surface received a deposit of highly reflecting silver. By this process Parsons produced mirrors of great efficiency and moderate cost, remarkable not only for their reflecting power but also for the accuracy of their parabolic figure. Made in many sizes ranging up to a diameter of seven feet, they have found, and still find, wide application. They bear the fierce heat of the arc lamp without damage, and their lightness makes manipulation easy. In one form the mirror is divided vertically in halves which can be adjusted to split the beam of light into two parts with a dark space between—an arrangement particularly serviceable in certain cases, as, for example, in assisting the passage of a ship through the Suez Canal.

Since about 1890, when the Heaton works were started, these reflectors have been a minor but by no means unimportant product. For long they were the only item which could be said to represent Parsons' concern with optics. But after the death of his son, who was killed in the last year of the war, a friend who saw his need of distraction, suggested that there was much useful work to be done in the manufacture of optical instruments and optical glass. This led Parsons to acquire a controlling interest in the business of Ross Limited, of which firm he became Chairman. As his interest in optical matters grew he went on to think about the construction of large lenses, and because he had ideas as to possible methods of making the necessary large disks of glass, he felt it would be advisable to be in a position to control the manufacture of the optical glass which he would require. It happened at the time that there was an opportunity of purchasing the Derby Crown Glass Works, which were instituted during the war and were producing optical glass of high quality. He bought them, and the firm has become well known as the Parsons Optical Glass Company. Experiments in making large disks at Derby were brought to a successful issue as a result of Parsons' ingenuity in devising new methods which are now in operation and are considered by experts to be of particular value. In the meantime he arranged for a partnership with Sir Howard Grubb & Co., the well-known makers of astronomical instruments, and established at Heaton a workshop in which telescopes of any size could be built, a site being selected close to the turbine works so that their machinery might serve for any heavy operations. This business was rapidly growing when he died. Using the glass made at his works in Derby, the firm had already completed a 36-inch reflecting equatorial for the Royal Observatory at Edinburgh, and was engaged on one of

74 inches for Toronto, as well as many more. In these multifarious activities there was no sign of waning interest or failing powers. Parsons could still bend his mind to unaccustomed tasks and find fresh solutions of old problems.

A pursuit which cost him much both in money and effort was the attempt to make diamonds. Under what conditions would carbon crystallize? The question attracted him as a physicist, and he brought to bear on it the resources of the engineer, with all his own skill and daring in experiment. As early as 1888 he described researches on carbon at high temperatures and under great pressures, the primary object then being to obtain forms of carbon which would be specially suitable for the electric arc and for incandescent lamps. Incidentally he obtained minute particles of a very hard substance, 'some compound of lime, silica, and carbon, or perhaps pure carbon only'. Further results were given in a paper of 1907 and in his Bakerian Lecture of 1918. Using a press which was placed for safety in an armoured chamber, he applied large electric currents to bring carbon to an intensely high temperature under pressures ranging up to 15,000 atmospheres; but it showed no sign of melting. Changing the mode of attack, he produced still more extreme conditions through the impact of a bullet fired into a hole in a steel block. In another series of experiments he tried to crystallize carbon *in vacuo*. So far as the formation of diamonds was concerned, all his attempts gave negative results.

If Parsons ever approached an admission of defeat it was here. Only a few days before he left England on his last voyage, he showed me—rather wistfully it seemed—a collection of natural diamonds he had lately acquired, in which each stone projected from its matrix of blue clay. Here was Nature's work. What was her method?

He was as far as ever from being able to tell. But I think he hoped to try again.

It was no doubt in connection with this inquiry that he suggested, in a Presidential Address to the Engineering Section of the British Association in 1904, the desirability and feasibility of sinking a deep bore-hole to examine the earth's crust. He discussed the procedure that might be adopted in boring to a depth of twelve miles, and the probable cost. Reverting to the subject in his address as President of the Association at the Bournemouth meeting in 1919, he remarked :

'The expense seems trivial as compared with the possible knowledge that might be gained by an investigation into this unexplored region of the earth. It might indeed prove of inestimable value to science, and also throw additional light on the internal constitution of the earth in relation to minerals of high specific gravity. In Italy, at Lardarello, bore-holes have been sunk which discharge large volumes of high-pressure steam, which is being utilised to generate about 10,000 horse-power by turbines. . . . It seems, indeed, probable that in volcanic regions a very large amount of power may be, in the future, obtained directly or indirectly by boring into the earth, and that the whole subject merits the most careful consideration.'

The address also refers to another of his scientific inquiries. It had been noticed that the propellers of ships were liable to a species of erosion which took the form of a pitting of the blades. In 1915 a committee was appointed by the Admiralty to examine this matter. Parsons, who was chairman of the committee, ascribed the action to the 'water-hammer of collapsing vortices', when the propellers were producing cavitation; in other words, to the intense blows which are struck upon minute areas of the surface of the metal when vacuous cavities

in the adjacent water suddenly close. He compares the phenomenon to the well-known fact that nearly all the energy of the arm that swings a whip is finally concentrated in the tag. At a later date, a pitting action which is observed in condenser tubes was found to be a possible consequence of the same cause.

In 1926 Parsons collected and republished the scientific papers of his father, giving an account of the great telescope at Birr and of observations made with it. The volume includes certain letters written in 1854, urging on the naval authorities the practicability of constructing a 'floating battery' or ironclad, an idea then apparently new.

The fertility of Parsons as an inventor is shown by the list of his British patents which number over three hundred. Turbines, electrical machines and their parts are the chief subjects ; but there are many more.

Among his minor devices was the Auxetophone, better known in the domestic circle as the Bellowphone. It was a loud-speaker which could greatly reinforce the sound of a gramophone or musical instrument, the vibration being magnified by means of an air-valve relay. A really loud loud-speaker, it was built long before loud-speakers became domestic pets or pests. A mention of it will be found in recollections by Lady Parsons which are quoted below.

Another early toy of particular interest was a little flying machine with a spirit engine working a propeller. This was made by Parsons in 1893 ; he gave an account of it in *Nature* of June 18, 1896, along with photographs which show the machine at rest and in flight. A feature of the engine was that the spirit vapour, after doing work in the cylinder, was not discharged into the air, but passed to a combustion chamber under the boiler, where it served as fuel to evaporate more spirit. The machine

had a tail and wings made of cane framework covered with silk ; the span of the wings was eleven feet. When gently launched by hand it would fly for a hundred yards or so, coming down only when all the spirit was consumed.

In 1884 Parsons married Katharine, daughter of Mr. W. F. Bethell, of Rise Park, East Yorkshire. She shared his anxieties and his triumphs, and was with him in his last journey. They had two children, a son—Major A. G. Parsons, R.A.—who was killed in action in 1918 at the age of thirty-one, and a daughter who inherited more than a little of her father's taste for mechanics. Lady Parsons writes :

' I first knew Charles in 1883. He was then working at Kitsons in Leeds where his brother Clere was a director ; he had recently left the Elswick firm where he had been a premium pupil. At Kitsons he had a small workshop and a mechanic and was experimenting with a torpedo. Charles had the character of being an extraordinary and weird young man socially, but it was understood he was a great genius. We were married in January 1884, and, after a few days' honeymoon, went into lodgings in Leeds. Charles was immensely keen about the torpedo and used to take the mechanic and me to Roundhay Lake at 7 A.M. There they spent hours trying the torpedo while I shivered on the bank.'

One is tempted to question whether the world sufficiently recognizes what it owes to the forbearance of great inventors' wives.

Lady Parsons continues :

' Charles was already thinking out the turbine idea. He made models from cotton reels with cardboard blades stuck on with sealing-wax. He was also trying new ways of winding dynamos. The turbine idea developed very rapidly and soon small experimental machines were constructed. But at that time Clarke, Chapman & Co. were

building up a business on other lines and could not encourage expensive experiments.'

And later :

' Charles used to make all sorts of amusing toys. "The Spider," a little spirit engine, carried on three wheels, that careered at a great pace round our lawn, with the two children, Charles, and three dogs rushing and shouting after it. A very pretty toy was a little flying machine with a spirit boiler. It was photographed in full flight, and the photograph has often been reproduced in "flying" papers.

' About that time Charles, who had never ridden a horse, thought he would come out hunting with me. He bought a hunter, knew nothing at all of horses or riding, and out he came. He was perfectly undaunted, galloped as hard as he could and charged everything that came in his way. That particular hunt still talks with amusement and wonder at his courage.

' We always had a workshop in our house where Charles spent most of his time at home, working till 2 or 3 A.M. The most trying time for the family was when he was producing the "Bellowphone". Strange and weird were the noises through the nights. The finished Bellowphone was a very sweet and beautiful instrument when played by him at home, with the sound coming through a gigantic trumpet. He used to place it in the garden, and people from miles round came flocking into our park to hear it. After that many experiments on the making of diamonds were undertaken both at home and in the works. He had immense faith in the possibility of making diamonds, and microscopic particles claiming to be diamonds were often shown us. In later years Charles, with his usual courage, admitted his diamonds were not the real thing.

' The outstanding feature to me of his whole life was his power of concentration ; nothing disturbed him when he was absorbed in a problem—no noises, no discomfort, no time, and no meals. He was perfectly oblivious to

them all. The other great feature was his sublime courage. He never admitted defeat; he was always hopeful about any concern he undertook, and looked forward, even in his last days, to making a success of the new kind of work he had undertaken when well over the age of 70 years.'

As was to be expected, the achievements and the personality of Parsons brought a host of honours and rewards. He was made C.B. in 1904, K.C.B. in 1911, and was admitted to the Order of Merit in 1927. He was elected F.R.S. in 1898, was a Vice-President ten years later, and was Bakerian Lecturer in 1918. He received the Rumford Medal in 1902 and the Copley Medal—the Society's highest award—in 1928. He was an honorary Doctor of many universities, including Cambridge, Oxford, Edinburgh, Glasgow, Dublin, Durham, Leeds, Liverpool, Toronto, and Pennsylvania. Other recognitions were the Albert Medal of the Royal Society of Arts, the Kelvin Medal, the Faraday Medal of the Institution of Electrical Engineers, the Franklin Medal of the Franklin Institute of Philadelphia, and the Bessemer Medal of the Iron and Steel Institute which was given him in acknowledgment of his services to metallurgy. He was President of the British Association in 1919. He served also as President of the Institute of Physics, and of the North-East Coast Institution of Engineers and Shipbuilders. In 1914 he received the freedom of the city of Newcastle.

He was a generous donor to the funds of many learned societies, especially to the British Association, the Royal Institution, the Royal Society, and the Royal Society of Arts. Shortly after the Department of Scientific and Industrial Research was established he became a member of its Advisory Council. Before that, he had been an original member of the Board of Invention and Research

which was set up by the late Lord Balfour in 1915 for the purpose of finding applications of Physics, Chemistry, and Engineering of a kind that would be of service during the war. Sir Joseph Thomson, who was another active member of the small central committee of that Board, bears witness¹ to the whole-heartedness with which Parsons threw himself into the work, and adds this appreciation :

' Besides being by far the greatest and most original engineer this country has had since the time of Watt, he was one of the kindest and most steadfast of friends, and his death has made in the lives of many a gap which will not be filled.'

With these words, as true as they are authoritative, this notice may appropriately close.

1931

¹ *The Times*, February 16, 1931.

VIII

THE UNIVERSITIES AND THE NEW ERA

FROM AN ADDRESS AT THE FIRST GRADUATION CEREMONIAL AFTER I WAS APPOINTED VICE-CHANCELLOR OF THE UNIVERSITY OF EDINBURGH, JULY 11, 1916

IN responding to an invitation to address you on this occasion, I am glad to know that I am following a precedent set by the late Principal. I hope it may often thus befall me to copy one whose memory is cherished with so affectionate a reverence.

It is with gratitude as well as pride that I find myself doing this first public act of service to our beloved Alma Mater. Like most of her children, I let go her skirts as soon as I could walk alone. I have wandered far, and now enjoy the traditional welcome of the returning prodigal. She has induced me to return—when, indeed, I was not thinking of it—by offering the fattest calf at her disposal. She has brought forth the best robe and put it on me—a robe in which Solomon might have challenged comparison with the lilies of the field.

This is no time for making merry, but one may be allowed to express a certain quiet gladness in renewing associations which have lost nothing of their power to stimulate and charm. It is forty-five years since I entered the University as an undergraduate. The memory is vivid of my first day of academic life. The scene was the address of a Lord Rector, Sir William Stirling Maxwell. Chosen by the students, and prepared to lay before them the ripe fruits of his scholarship, he found them a

hostile mob who would not listen to a word he had to say. I asked the reason, and was told he had voted as they disapproved on what was the burning question of that day, the admission of women to study medicine. And now, when I come back after nearly half a century, I find that the chief question for consideration is still the admission of women to study medicine. It would seem that the mills of the University grind slowly. There is an absence of hustle which recalls the operations of geology or the evolution of species.

For nearly two generations the lady medicals, as they were called when I was a boy, have been wandering in the wilderness. Must the tale of weary years be extended, or is the land of promise now in sight? Let us hope it is, and that they will enter the land and enjoy it without injury or loss to the existing occupants.

You of a later civilization are no doubt less intolerant than those who refused a hearing to the Lord Rector of 1871. But I trust and believe that the soul of undergraduate life remains as ardent as it was then, that to come up to the University still stirs every young spirit as it stirred mine, that the consciousness of intellectual expansion is still as glorious, that the springs of thought and feeling and action still respond as they did to the influences of the place. Now, as then, Edinburgh makes its appeal to the aesthetic sense; now, as then, it fires the historical imagination. And if its students no longer have the good fortune to sit at the feet of a Lister or a Tait, teachers are never lacking who are worthy of that whole-hearted enthusiasm which gives the University its proper hold upon the minds and the affections of its sons.

The time has come for some of you to pass out into the bigger school of life. If you have studied to any purpose here, you will take with you the power to learn lessons which are awaiting you in that bigger school. . . .

In the circumstances of the time you go out with a special inspiration. We live at present under the spell of a dominant motive beside which all the usual impulses of conduct are trivial. You are about to play your several parts in the greatest struggle the world has ever known. There are some here who envy you the chance of such action as is the privilege of the young. But, young or old, the burden of the war presses on us all, and while we strive to carry it we are conscious of a new birth. The war has given life a seriousness of purpose which for many was not there before. It has altered our standards of moral value. It has cut away rank growths which obscured the vision and encumbered the steps. It has given us a truer conception of social responsibility. It has swept aside much of what was mean, petty, sordid. It has convinced us of the duty of sacrificing self. It has made us face great issues with courage and sincerity. May I not say that in the personal experience of many persons here there is a sense of spiritual regeneration, that out of the misery and cruelty and madness of the war there comes a cleansing and uplifting of the heart ?

There is some soul of goodness in things evil,
Would men observingly distil it out.

Observingly or unconsciously we are all affected, and so profoundly as to give hope that the soul of goodness will prove more enduring than the evil from which it is distilled.

One's thoughts turn to those who in normal circumstances would have been here to-day. The Universities have taken a big share in the war by sending of their best. Our nearly empty halls are witness to this, and we are proud to think they are so empty. More than four thousand members of this University are serving with the forces: more than three thousand hold com-

missions as officers. There are many who can never come back. They have given themselves freely, even cheerfully. They have died—they are dying—so that what they and we hold most dear may live. They have found their kingdom, and who shall pity them? To those who do come back life can never be the same again. It will be coloured by the memory of adventure, it will be ennobled by the sense of renunciation. To them will apply the words the poet uses of the Happy Warrior :

Whose high endeavours are an inward light
That makes the path before him always bright.

May we not then turn hopefully to the future? The influence of the war on our social fabric can be compared to an effect one sometimes sees in the study of metals. Let a piece of metal be heated under certain conditions, and almost suddenly a great internal transformation occurs. Its external form shows no change. In the last analysis of the chemist it is still the same substance. The same molecules are there, but silently and invisibly they have marshalled themselves into wholly different patterns of structure. In a very real sense the material has become new. Its old attributes have disappeared. What was hard and brittle is now plastic : it may readily be shaped into other forms : it is capable of uses to which it could not have been put in its former state. The effect is a permanent one, persisting after the conditions which produced it have been removed.

Is there not some parallel to this in the new-made world that awaits us after the war, in the changes, spiritual, social, political, economic, industrial, educational, that are even now taking place, and must increasingly take place in the early years of peace? When our civilization, which is now straining to save itself, settles to the task of reconstruction, will it not find men's minds

more plastic, traditions less controlling, prejudices less final? The community has adapted itself marvellously to war. It will be under an equally stringent obligation to adapt itself to peace, not in the old ruts, but conscious of new wants, new duties, new powers.

Amongst many other changes we may expect to see a revision of methods and aims in education. If the war has demonstrated some of the good fruits of our schools and Universities, it has also laid bare defects which we must set ourselves to make good. It will lie with the Universities not only to act as guides of public opinion, not only to make their influence felt by the schools, but to see to it that their own house is in order. Is it too much to hope that they will show the plasticity which will be required of every element in the State during that anxious period of reconstruction, and that in the process they will not lose any of those essential qualities we venerate and love?

I am no prophet, but it needs none to affirm that the Universities will continue, as ever, to be sanctuaries of the spirit of man, where he may learn how to live not by bread alone. They will continue also to be places of research, prominences from which to gaze into the unknown, outposts from which to advance in the conquest of territory now unexplored.

But while these basic features remain, may we not look in the future work of the Universities for a more direct relation to industrial requirements and economic problems? The war has given a marvellous impulse to productive activity, but the current for the most part now floods a single channel, from which it must be diverted when the demand for munitions abates with the coming of peace. It must then be turned into other streams, in which it may swiftly re-create the wealth that has been destroyed. In this process the Universities have

a great part to play. It will be for them to promote industrial efficiency, to revise the dogmas of political economy in the light of a broader ethic, and to give such teaching as may lead capital and labour alike to strive, in no spirit of antagonism, for an end which will need their sanest co-operation. Again, it will be for the Universities to bring science to bear on manufacture, to see that no barriers are allowed to come between the laboratory and the workshop, to promote the nuptials of theory with practice. *Fas est et ab hoste doceri.* In these matters we have much to learn from the Germans. Students of the subject have known for years that we have been behind Germany in the technical application of science, and especially in realizing the extent to which industry should be founded upon and guided by the results of research. The war has brought this lesson home to a wider public, and opinion is ripe for reform. It rests partly with the manufacturers and partly with the Universities to see that this handicap to national prosperity is removed.

No review, however brief, of the situation as affecting the Universities, can omit to notice the place women are taking in public and industrial life. In their response to the nation's call they have shown capabilities and adaptability beyond expectation. The range of their activities is no less remarkable than the devotion and courage which have levelled mountains of obstacle. Many of their present occupations must be transient, but it cannot be expected that all will come to an end. We may surely welcome the prospect of a permanent increase in the army of productive workers. If so, the responsibility of the University in providing higher education for women is enlarged, and it becomes more than ever necessary to study how best to meet their special requirements.

In these and other ways the Universities of the future have tasks to perform which are worthy of their powers.

It is probable that a larger proportion of the people than before will seek to obtain the higher education. It is certain that all will be less able to pay for it. This may throw on the Universities of Scotland a relatively large share of the common work, for their boast has always been that their doors are open to the poor. We cultivate the Muses on a little oatmeal. Our Scottish virtue of thrift, which provides that indispensable modicum for not a few deserving sons, has at last come to its own : its praise is on all the hoardings. It is an austere virtue, but an excellent one, and a strong ally to education. More attractive, perhaps, and a still more powerful ally, is another national characteristic, the devotion to learning which for generations has permeated all ranks of our people, which made Scotland a land of Universities when Universities were rare. Long may that robust passion for knowledge bring to the University of Edinburgh, not from Scotland only, but from the Dominions beyond the seas, a crowd of those who are destined in due course to pass out bearing torches kindled at our shrine. They go their several ways : there is no corner of the Empire where they are not found. The torch in each man's hand may in time serve to guide his fellows ; it may spread illumination over some region, great or small, of the world into which it is borne. In any event, let him but keep it burning, and with its light about his own feet he will walk serene.

1916

The following Addenda are taken from Addresses to the Graduates on two subsequent occasions.

(October 1917.)

I ventured last year, as a new-comer, to chaff the University—if one may use a word so colloquial in relation

to a body so august—for dealing with the question of admitting women to the study of Medicine in a manner deliberate enough to recall the operations of Geology. But even in Geology the uniformitarians do not have it all their own way : there are such things as volcanoes and earthquakes. In this matter the seismic influences of the war have been irresistible. The walls of that Jericho were already crumbling ; it was not my impudent trumpet that brought them down. In fact, they fell in time for women to be admitted at the beginning of the session, and satisfactory arrangements have now been made for giving to women, in respect of clinical as well as academical instruction, precisely the same facilities and privileges as men.

(*April 1918.*)

In congratulating the graduates on completing their course, it may not be out of place if I refer to the special difficulties they have overcome. Even in normal times the end of a term has its trials. Examinations have to be faced when the interest has ceased to be fresh, when the nerves and temper alike of teachers and taught are a little jaded. In your case the strain has been accentuated by the circumstances of an unparalleled time. Instead of being free to give your whole minds to work of a kind that requires concentration, you have been preoccupied by the anxiety through which the nation is passing. It cannot have been easy, or even possible, to do your best amid the distractions of so grave a crisis.

I would go further and venture to express my sympathy for all the students in this, that their University life should be lived at a time when there is so much to check and qualify the joyousness of youth. One who remembers well what the undergraduate years meant to himself

cannot but be sorry that you, in your turn, should lose something of their quality. It would be absurd to suggest that the war has taken away all lightness of heart: your spirit is too elastic for that. But the war does defraud you in some measure of a natural heritage that should be enjoyed to the full in these quickly passing years.

That is your loss. But in compensation you have gains which are also consequences of the war. Let me refer very briefly to two of these gains.

In the first place, the war has brought about an increased appreciation of early manhood. There is a revision of social values; a revision that assigns to young men and young women a place of greater consideration in the body politic. War teaches us older folk somewhat sharply what are our own limitations. It awakens us to what the younger members of society can do, not simply to their potentiality as the citizens of the future, but to their capacity for present-day service to the State. They are recognized as immediately effective, to a degree that was not understood until the necessities of war revealed their powers. There has perhaps never been a time when youth held so high a place in general esteem. This fact may rightly give you encouragement. On the other hand, it opens up dangers to which you will not be blind.

In the second place, you should, I think, reflect that the war has given you an unexampled opportunity to shape the world according to your most inspired dreams. Civilization is to-day profoundly conscious of its failure: it is eager for amendment. Much of its structure is shaken and cracked, and must be rebuilt in new patterns. It is on those who have lately reached or are now reaching maturity that a great part of the task of that re-building must fall. The world knows itself to be out of

joint. That you were born to set it right is no cursed spite : it is a unique privilege, a call to which you may worthily dedicate all that is best in you.

To most University students, in normal times, the clearest call is an intellectual one : ambition and taste alike point the way to achievement through letters or through science. But I think many of you to-day must be very conscious of a social call. I do not mean only the call of the moment to some form of war service—that you all hear. But looking further, beyond the duration of the war, you are beckoned to play your part in the social reforms for which the world is ready. Some of you, I know, are fully alive to this obligation and anxious to prepare yourselves for it by special study of the questions which any attempt at reform will involve. You realize that change is in the air ; and that with wise direction and zealous service, change will mean betterment. The poet has spoken of boyhood's splendid visions fading into the light of common day. It is your happy fortune to share visions which need not, and will not, all fade. Nor will you be content to look on while they assume form and substance : by your own efforts you will contribute towards making the visions real.

IX

A LAY SERMON

PREACHED TO THE UNIVERSITY IN THE CATHEDRAL
CHURCH OF ST. GILES, EDINBURGH, JUNE 1, 1930

MY text is taken from the 8th Psalm at the 3rd verse :

‘When I consider Thy heavens, the work of Thy fingers, the moon and the stars, which Thou hast ordained; what is man, that Thou art mindful of him? and the son of man, that Thou visitest him? For Thou hast made him a little lower than the angels, and hast crowned him with glory and honour. Thou madest him to have dominion over the works of Thy hands; Thou hast put all things under his feet.’

And to that I add a passage from the 2nd chapter of the Epistle to the Hebrews, at the 8th verse, where the writer, after quoting this psalm, makes a comment on it containing these words :

‘We see not yet all things put under him. But we see Jesus . . .’

It is no light thing for a layman to be called upon to utter his own thoughts from the pulpit of this national shrine. And the responsibility is all the greater because I speak as one in the twilight to those for whom dawn has but lately turned into day. Your day brings its own difficulties, its own perplexities. The problems of a post-war world are, many of them, new as well as urgent. Some—perhaps the gravest—have arisen as social or

political effects of discoveries and inventions made since my generation was young. But there are also fundamental problems of thought and conduct that go on from age to age. You, who are now learners and may soon be leaders, will find, each for himself, that the new knowledge goes but a little way towards settling the old questions. Each of you must still grope, just as we did, after his own philosophy of life, and still strive, however imperfectly, to live up to what he recognizes to be best.

When we read this Psalm we are struck with its literary quality. It is an example, one of many in that precious heritage the Authorized Version, of lofty thought set in the most fitting words. The phrases of the Bible are woven into the fabric of our speech as closely as its ethic is woven into our lives. In any language the Bible must be beautiful, but our translation has a beauty that is all its own. It is a commonplace to say this, but do you sufficiently value the English Bible as an incomparable piece of literature ? Here, I venture to think, we of an older generation had an advantage which some of you may not have shared. We were brought up on the Bible : its stories, its people, its parables were household words. Some of the notions which the child imbibed were inevitably modified in later life, but I for one will never cease to be grateful to those who gave me an early intimacy with this matchless book. It should be read as you would read any other classic, with intention to discover all its meaning. In such reading you have one advantage which the young men of my period did not have. Thanks to recent critical researches, you have abundant help towards a better comprehension. The results of modern scholarship have been put into forms which make them available to people who are not necessarily scholars themselves. I believe you will find

them, as I have done, of intense interest ; they will remove difficulties and lead you to clearer views.

Turning now to the substance of the Psalmist's thought, we find him swayed by two emotions : on one hand, the insignificance of man in the presence of nature ; on the other, the greatness of man as endowed with some part of the quality of God. He asks us to contemplate a tremendous antithesis :

' When I consider Thy heavens—what is man that Thou art mindful of him ? '

And yet, ' Thou hast made him a little lower than the angels, and hast crowned him with glory and honour.'

The contrast stirs his imagination. How strange that man, this speck in immensity, this almost nothing, should be put in dominion over God's works and possess in some measure the attributes of godhead. Here is a mystery which stirs our imagination still. To us indeed the mystery is greater, for we realize increasingly the vastness of the material universe in which man plays his tiny part.

From the earliest days astronomy has made an appeal to the emotions as well as the curiosity of thinking man. The heavens have declared the glory of God to the Psalmist and to many devout minds after him. Perhaps some of us are now more ready to find God in other ways, not so much in the grandeur of His works, not so much in the wind and the earthquake and the fire, as in the still small voice which every man, if he will but listen, may hear within himself. But the sense of awe that comes with contemplation of the stars cannot fail to be quickened by what telescope and camera exhibit of the multitude of stellar systems, of the birth and decay of universes in the unplumbed depths of space. One's imagination reels before the arithmetic of the astronomer. The earth is but a grain, and the past of humanity is

but a moment, when tested by his scales of space and time. When we consider the heavens, what, indeed, is man?

And yet, take man as he is, a creature of yesterday in the history of matter, we nevertheless accept without question the Psalmist's hymn of praise: 'Thou hast made him a little lower than the angels.'

I understand these words to mean: 'Thou hast endowed him in some measure with divine attributes.' Man's crown of glory is that he has something in him of God. It is this that enables him, however dimly, to see God.

The evidence of God which comes by listening to the voice within is a type of evidence transcending that of the senses. From the messages which the senses bring we infer that there is an external world. But the thing that perceives is more fundamental than the thing perceived. Thus we know that there is mind far more directly and more surely than we know that there is matter. So, too, I think we know more surely that there is God. An intuitive recognition of God is found in man throughout the ages; it lies at the basis of all religions. It is often said that man makes God in His own image. That is true. But may we not say that man makes God in his own image only because God has put into man's soul some portion of Himself?

Notice how even the mental endowment of man places him in a category apart. From it springs his knowledge, his philosophy, his invention. The very science of astronomy by which he measures and weighs the heavens, if it demonstrates his insignificance is itself evidence of his intellectual power. His unflagging pursuit of truth has its reward. Year by year it brings him to a better understanding of the works of God's hands and a fuller dominion over them. It is part of man's glory that the

effort goes on : the dominion extends but is far—very far—from complete.

In no department of knowledge is there finality : the latest word is never the last word. Those who are striving to advance are like mountain climbers on a buttress of difficult rock. The step we are gaining, or have just gained, interests us most. We look upwards and trace doubtfully a step or two above : we do not see the top. As we rise the view widens : the country below looks different ; landmarks that were once prominent have disappeared. In physical science, for example, the outlook of the twentieth century is almost unrecognizably different from that of the nineteenth. The physicist is faced with dilemmas which he cannot reconcile. In such a situation there is no room for intellectual arrogance or dogmatic assertion.

In the science of life, we know nothing of origins, nor indeed of what constitutes the distinction between living and not-living things. Of the relations of mind to matter we do not understand the barest rudiments. How the conscious will can affect material events, can play, as it were, the part of the pointsman to the moving train, is a mystery to which as yet we have not any clue. To the student of science every example of this common experience is none the less a miracle though habit dulls us to its wonder. When familiar things are so incomprehensible, we do well to put dogma out of sight and out of mind.

Man's dominion over nature—so far as it goes—is a dominion not only of knowledge but of use. Much of it is beneficent, but the war and other lessons have taught us that it may be prostituted to ignoble ends, and that it carries within itself untold possibilities of disaster.

And why ? Because man's dominion fails just where the need for it is most urgent : he has not achieved

dominion over himself. The ingenuity of the human race has developed faster than its moral sense. Discovery, invention, these exercises of the intellect do not bring righteousness or spiritual grace. Man has less than a child's innocence and much more than a giant's power. 'We see not yet all things put under him.' He is not master of himself.

I have touched on one special menace. But, apart from that, how much of man's history, collective or personal, in peace no less than in war, is a record of folly, of selfishness, of sin? 'The good that I would, that I do not : the evil that I would not, that I do.' Dare any of us say that these words have no application to himself? Who is not conscious of moral failure and fatigue? Which of us is truly captain of his soul?

Where, then, shall we turn? The answer comes in the last words of the text: 'But we see Jesus.'

We see Him as a living figure—still our guide and stay. His message is never out of date. He has been well called the eternal contemporary. Has the human race any greater glory than this—that into it He was born? And for each of us is there any higher honour than to accept the sonship which Jesus invites us to share?

In the message of Jesus to mankind no feature stands out more clearly than His insistence on the Fatherhood of God. The record shows that His own special sense of sonship inspired His mission, dominated His life, coloured all He said and did. He invites us also to be sons of God. But to share that sonship we must become worthy: 'I say unto you, Love your enemies . . . *that ye may be the children of your Father which is in Heaven.*' Again and again does Jesus speak of God, to those who will listen, as 'Your Father'. When asked by His disciples to teach them how to pray, He replied, 'When ye pray say "Our Father"'. The words are so familiar we may easily

miss what they imply. For these two words, 'Our Father', seem nothing less than an epitome of religion in its double aspect—love of God as Father ; love of our neighbour as a fellow son of God.

When we look at Jesus we see the greatest figure in history, by far the most influential of those who have shaped the course of the world's events. Judged by its effects, there is nothing to match the significance of that brief ministry. The force of His message, the nobility of His life, the magnetism of His person, had secured the devotion of a little band of followers. In the tragic moment of His condemnation to the Cross they forsook Him and fled, believing, so it seems, that His death would be the end. It was not the end. Something happened, outside the range of their expectation and of ordinary experience, something which convinced them that the buried Jesus was still their living Master. In a few days or weeks we find them reunited, exultant, strong with a new strength, determined at any risk and through any hardships to serve Him and preach Him to the world. Whatever difficulties the historian may see in the fragmentary stories of the Resurrection, and whatever interpretation may come to be put upon them when we begin to learn something about the relations of body to spirit, the cardinal fact remains that an emotional experience of overwhelming intensity changed the current of these men's and women's lives. St. Paul, who appears to have been the first to have put that experience on written record, claims explicitly to have shared it. The scattered, hopeless followers of Jesus were transformed into a confident missionary band. Prejudice and persecution only fired their zeal. Unflinchingly they challenged the world—first their little world of orthodox Jews, and then the whole Roman Empire, steeped in its long-established polytheism. Marvellously their gospel spread. The

Galilean conquered. At the outset they thought mistakenly that the risen Christ was quickly to reappear on earth with acknowledged authority. That hope soon faded ; it was only the first of many errors the Church has survived in the course of nineteen centuries. The essential faith in Jesus as a living Lord was not shaken : it abides now as a personal conviction of every Christian. That is why Christianity continues to act as a force shaping the world. Jesus is no mere figure in history. He is alive in the hearts of His followers. His Church has come far short of the Founder's ideal : it has not escaped the intrusion of unholy things, perversions, corruptions, crimes. It has undergone reformation—as these walls bear witness—and we may well hope it will undergo reformation again and yet again. Nevertheless it persists. Check and pollute it as men may, it springs still, a well of living water, the perennial source of a stream of tendency that makes for righteousness.

It is not till we apprehend something of the character of Jesus that we realize how noble man might be and how poor, by comparison, he is. We are bid to follow, but the best of our attainment falls sadly short. To each of us the call comes, that we should strive towards heights which Jesus has revealed. What though none of us can reach them ? No effort will wholly fail, and each step gained will help towards the next. To accept the sovereignty of Jesus cleans and hallows common things. It puts us in a changed relation to our fellows.

To-day the world is weary and heavy-laden. It is conscious of problems which seem insoluble and burdens which threaten to become greater than can be borne. The problems would be made easy and the burdens light could but men, and nations, learn to rule themselves in the spirit of the teaching of Christ.

X

THE FLEEMING JENKINS AND ROBERT
LOUIS STEVENSON

I

FORTY-FIVE years ago,¹ when he was a young man just finding his feet in the world of letters, it was my good fortune to meet Louis Stevenson fairly often at the house of a friend to whom we both owed much. The friend was Fleeming² Jenkin, his senior by seventeen years, whose Life he was afterwards to write—the ‘Cockshot’ of *Talk and Talkers*—the Professor of Engineering to whom, half-a-dozen years before, had been entrusted the impossible task of making Stevenson an engineer. From the Professor’s lectures Stevenson had been a sedulous truant: they were perhaps the least considered item in what he has called the vast pleasantry of his curriculum. ‘No, Mr. Stevenson,’ said Jenkin, when asked for a certificate of attendance, ‘there may be doubtful cases; there is no doubt about yours. You have simply *not* attended my class.’ But Fleeming Jenkin was much more than an eminent engineer and (as I can testify) a most inspiring teacher of engineering. His interest in art, in literature, in personalities, in all that makes up life, was unbounded; his judgment was penetrating and sympathetic. He had the discernment to see promise of quite another sort in the casual youth to whom every professor was a joke

¹ Written in 1922.² Pronounced *Fleming*.

and Jenkin himself ' perhaps the broadest '. Stevenson had already met with some kindness at his hands, and counted on easy acquiescence when he asked for the certificate. But so honest a refusal startled him into respect. He saw for the first time the ' extreme dignity of goodness ' which, with unfailing affection and equally unfailing shrewdness, fitted Jenkin so well for the rôle he was often afterwards to fill of confidant and mentor. And so began a friendship that did much to temper with sweetness and sanity Stevenson's early years of struggle and revolt.

A foundation for the friendship had been laid before Stevenson became a nominal student of engineering. It was in the winter of 1868 that Mrs. Jenkin, then a newcomer to Edinburgh, had discovered Louis while she was returning his mother's afternoon call. She has told how in the gloaming Mrs. Stevenson had seemed to be alone, but suddenly from out of a dark corner came a voice, peculiar, vibrating, talking as Charles Lamb wrote. She stayed long, enchanted by the conversation of the ' young Heine with the Scottish accent ', and in leaving saw him clearly for the first time by the light of the street lamp before the door, ' a slender, brown, long-haired lad, with great dark eyes, a brilliant smile, and a gentle deprecating bend of the head '. She asked him to come and see them, and the reply was, ' May I come to-morrow ? ' Then she ran home and announced to Fleeming, ' I have made the acquaintance of a poet '. Louis came next day : it was the first of many visits to a house in which he found solace and profit and delight. Years after, in a letter written to Mrs. Jenkin on the death of her husband, his postscript was a veritable cry from the heart : ' Dear me, what happiness I owe to both of you ! '

I would wish these reminiscences to be in part a tribute to those two dear and notable people, to whom my own

debt is incalculable, whom I knew far more intimately than I ever knew Stevenson. Whatever recollections I have of him are inextricably mingled with memories of them. It may be said that their influence in forming the character of Stevenson was admittedly so great that those who admire and love him will wish to know more about them, to understand something of the causes of that influence and of the circumstances in which it took effect.

To both of them indeed he owed much happiness, and other things perhaps more important than happiness. It was a liberal education for any young man to associate with Jenkin and his gifted wife, an enriching experience, a sharpening of even the sharpest wits, a training of mind and taste, of manners and morals. The dullest visitor to the house must have been conscious of its atmosphere of distinction—intellectual, aesthetic, ethical. Some may have found the atmosphere too rare for comfortable breathing : but for Louis it was the breath of his nostrils. To the rebel of the seventies the Jenkin home was a haven, an oasis in a desert of convention and prejudice, whither he might bring his unrest, his self-doubts, his dreams. There he was valued, encouraged, criticized in a spirit of understanding, affectionately admonished, helped. Fleeming Jenkin had himself come through troubles ; he had fought his difficulties with indomitable resolution, and already, though barely forty, he had won a place in his profession equivalent (so he told me when as a student I consulted him about the prospects of a young engineer) to that of a bishop or a judge. He had force, experience, maturity, had done much and thought much. His life was filled, one would have said, with an incessant round of creative activities. In partnership, both as consulting engineer and inventor, with Sir William Thomson—afterwards Lord Kelvin—

he had wide and lucrative professional interests outside his professorship. The applications of electricity were then in their infancy : in that field and in others his mechanical ingenuity, his grasp of essential principles and flair for turning them to practical account, his aptitude for scientific research, made him an acknowledged pioneer. Edinburgh, and many other cities after it, owe to his initiative their Sanitary Protection Associations, which in the later part of last century did much to correct faulty plumbing and other errors of domestic sanitation, and so brought escape from much prevalent disease. The first idea of such an Association was Jenkin's. He created the Edinburgh Association, demonstrated its usefulness, preached its gospel, and was active in making it a pattern for other towns to follow. But he had too many facets to confine himself to engineering. His writings on other subjects—economics, literature, the drama, Greek dress, English rhythms, the atomic theory, natural selection—are evidence not only of his variety but of his insight, of his ability to throw fresh light on anything he took up. His essays in the *North British Review* on Darwin's *Origin of Species*, on Munro's *Lucretius*, on Matthews Duncan's *Fecundity and Fertility* were so suggestive that in later editions the authors admitted their debts to the critic. He was always intensely alive, vivid, unflagging, virile, doing with all his might whatever his hand found to do—and his arm had a long reach. He seemed to enjoy every minute of work and play. His joy in living was reflected in his talk, which was always ready and forceful and often witty, and in his buoyant optimism. He was ever on the alert to do a kindness ; a man of scrupulous honour ; a moralist whose own life was his best sermon. He revelled in friendly disputation : would take hard knocks with unruffled temper, and counted—not always prudently—on his disputants doing

the like. Companionship with Stevenson was easy to one who had never lost the gusto of a boy, who in middle life kept the sense of drama, the love of romance, the simple frankness of a child.

II

Fleeming worshipped his wife, and those who had the happiness to know her could well understand the worship. The only child of a distinguished civil servant—Alfred Austin—she had been brought up in an environment that developed her remarkable powers of mind and graces of spirit. Of all his pleasures I think the greatest was to draw her out, to provide opportunity for the display of her gifts, to direct on some suitable object the play of her delicate fancy. Her humour was as graceful as it was gay. I have never known talk that equalled hers in well-bred brilliance, in distinction of feeling, expression, and thought. One has heard Fleeming described, in the looseness of a Savile Club superlative, as the best talker in London ; but on occasions when his wife was at *her* best he was content to suppress himself and be her foil. None of the listeners would have wished it otherwise. Mistress of many languages, including Greek, she read much, and though she often followed the dictum which bids those who hear of a new book read an old one, she kept herself throughout a long life in discriminating touch with every literary movement. To hear her read verse or prose aloud was to enjoy a revelation of its meaning and music. What she was as an actress will be spoken of presently. Her households, in Edinburgh and in the Highlands (they both loved the life there, and Fleeming was a keen sportsman), always seemed to run on wheels : in domestic management she had the art that conceals art. A devoted mother of three sons,

she lived to take pleasure in watching, as from a central eminence, her grandchildren reach maturity, gently contriving to help them shape their lives, unconsciously communicating to them something of her own nobility. She had the grief to see two of them fall victims in the war. It was only in 1921, at the age of eighty-three, that she was taken from us, mentally active to the last, responsive to new fashions of thinking in a degree that excited one's envy, an interested spectator of affairs and a deeply interesting commentator on them, kind and sweet and understanding as she had always been, maintaining to the end her thoughtfulness for others, her love of truth and beauty and goodness.

She wrote little, and said she could not write. There are published fragments which prove she could : an article on 'Highland Crofters' in *Good Words* for 1885 ; the account of her discovery of Louis ; some early reminiscences of Lord Kelvin¹ ; these show a sure literary touch and make one wish for more. Her letters had always an individual charm, but I doubt if they would convey to those who did not know her that sense of her being a really great lady which came from her speech and her presence. I venture to copy two of them, far apart in feeling and in time. The first was written some two years after I had left Edinburgh for Japan. Fleeming and I were in frequent correspondence, and in a letter to him I had referred to a promise that she should write :

'I do not despair of Mrs. Jenkin's letter yet. Perhaps it would be better to say "note" than "letter". A note is not so dreadful as a letter. It is a thing you write while you are waiting for dinner, or between the visits of two friends. Encourage Mrs. Jenkin to think of it as a note, and then it will come.'

¹ See p. 171 of this volume.

It did come, by return of post :

3 GREAT STUART STREET, EDINBURGH,
Feb. 13 [1881].

A note ! Of course, my dear Mr. Ewing, I can write you a note. One note ? Twenty, if you would care to read them.

Why did none of you people who have been in distant parts, you and Fleeming, ever before tell me that it was possible to send a *note* to Japan ? I thought it had to be a *letter* of eight sides on that thin paper which holds one's pen fast and lets all one's thoughts through ! And so I have gone about quite sad, thinking that you would first be vexed with me and then forget me—unable to rejoice, as I should otherwise have done, in my exquisite tea-pot with the mouse atop —feeling quite ashamed before my dear little cups—Fleeming's paper-knife a reproach to me—the phonograph a pain—plays rapidly becoming unbearable : and all because I was never told that I could write a *note* to Japan !

Do you not owe me many apologies ? Indeed you do, very many, very humble ones. Or is it I who owe them to you ? Lest it should be so, I hasten to forgive you and to beg that no more may be said about it. Nay, I insist, and to prove to you that I am sincere in accepting your apologies I write this note, and perhaps shall write others.

Only I hear that you are coming back possibly. I shall be glad when that day comes. I shall love to be introduced to your wife and to the pretty baby, whose photograph I know by heart. I send to both my best greetings.

Fleeming writes you of us. My life goes on, busier and busier I think. The boys seem to want more of me instead of less. They are turning out excellently well. Austin is as good and gentle and kind as he is big. He is very happy at Cambridge. (Letters to Cambridge take much of my time. Cambridge has not the Japanese privilege of notes.) Frewen and Bernie are at home still. This winter I am busy doing what do you think ? *Lecturing*—giving health lectures to a class of poor women and girls, and Frewen does my experiments for me. We have plays, as of old. You heard of my week of triumph in London with the *Agamemnon* ?

Jack barks. All goes on as usual. When you come to see us—as you and Mrs. Ewing must come, when you come back—

you will not believe how long you have been away. You will have to count the six little teeth to make sure you have been away at all.

But my note begins to grow to a letter. Again all kind messages.—Yours,

A. J.

The other was written a few weeks before she died, when she knew that the summons had come :

12 CAMPDEN HILL SQUARE, W. 8,
Dec. 23, 1920.

MY DEAR SIR ALFRED,—You have sent me a most beautiful present—a most uplifting letter.

At first I felt as if it were too beautiful—that I had no claim to such praise, to such sympathy—and then, as I read and reread it, I more and more seemed to understand how you, so clearly seeing and judging, had seen that in me whatever was good had come to me from those with whom I had lived—my father and mother and then my husband ; and so your beautiful praise became not my praise (though that is very precious to receive) but a recognition of my debts to them, and so to be rejoiced in with thankfulness. Fifteen years we delighted over you together, and then came the thirty-five years during which I have felt and known you would help me and my children—as I always have known. And now comes the wonderful praise which shows me that my life has not been useless.

It also helps me—coming now—by showing me that my friend, who can think, thinks much as I do of Death—a superb crown to life if we will but hold it in faith and courage.

One sees more deeply and hopes more highly as the strange hours pass. And one is happier if one is loved and thought of as I am, by my children and by my most faithful friend.

I shall try to send you a few words by and by. I shall not need to *try* to send you and Nellie and the little son my thoughts.—Yours,

A. J.

Her husband had died in 1885, suddenly cut off when at the summit of his powers. Here is a characteristic letter from him, one of many received while I was in Japan. My wife had been gravely ill : I was anxious

about our future ; had confessed to low spirits, and used an engineering phrase about the 'permanent set' that comes of overstrain :

SAVILE CLUB, 15 SAVILE Row, W.,
June 30, 1882.

MY DEAR EWING,—I feel a call to preach. 'Permanent set towards anxiety.' I must use strong language. No ; you might be ill or worried when you get this letter, so I won't. But just give it up resolutely. 'The coward dies a thousand deaths' is applicable to every kind of misfortune as well as to death. And the Christian 'take no thought for the morrow' applies particularly and specially to this kind of thing. Live your life gaily. When misfortune comes, suffer like a man, and cast the suffering away as soon as you can ; but a life spent in scanning the horizon for conceivable storms is not wisely led.

Our will is master of that sort of thing, believe me.

As regards bread and butter a man like you has simply nothing to fear. Come home as soon as possible. There is an immense stir and more coming. . . . I am collaborating with Ayrton and Perry in a big locomotion scheme whereof more soon. Gas-engine drags along slowly : its nose is put out of joint by this new electrical affair. We all flourish. This is not a letter but a sermon.—Yours affectionately,

FLEEMING JENKIN

Stevenson, as every one knows, wrote a biography of Fleeming Jenkin, to my mind one of his most perfect books. But the summary of his friend's character which he sent to *The Academy* immediately after Jenkin's death may not be so generally known. These are the concluding sentences :

' In talk he was active, combative, pounced upon his interlocutors, and equally enjoyed a victory or a defeat. He had both wit and humour ; had a great tolerance for men, little for opinions ; gave much offence, never took any. Behind these outworks of unresting, insurgent intellectual activity, his heart was deeply human and, in latter days, unaffectedly pious. He was of the

most radiant honesty and essentially simple ; hating the shadow of a lie in himself, loving the truth, however hard, from others. He had in his manners with those whom he loved a certain curative causticity, of which they learnt to be proud, and which he looked to have returned in kind. He would not nurse a weakness either in himself or in you. He knew you, and would not dissemble his knowledge ; but you were aware that he still loved you, and that it was thus that he desired you to return his affection ; hand to hand, not gloved. To those who did not know him, to people of weak nerves or of a vulnerable vanity, he was at times a trial. To those who did, who had learnt with what severity he judged and with what continual care he sought to correct himself ; what tolerance, what wisdom, what loving-kindness, he kept at the service of his neighbours ; in what a true relation he lived with his friends ; in what proud and chivalrous sympathy with his wife and sons : to those the sense of his loss must be incurable.'¹

Later, writing to Sidney Colvin from Honolulu in 1889, he says :

' I owe you and Fleeming Jenkin, the two older men who took the trouble and knew how to make a friend of me, everything I have or am.'

III

Such were the friends under whose roof I made the acquaintance of Stevenson. I too had been a pupil in Fleeming Jenkin's class, having come up to enter the University as a student of engineering in 1871, the session after Louis had been refused his certificate. I was a youth of sixteen, who brought no introduction ; but I soon became aware of the beginning of a friendly regard, which in my case owed nothing to truancy.

¹ *The Academy*, June 20, 1885.

An essay on the Relative Merits of the Wet and Dry Systems of Sewerage seemed to take the Professor's fancy. Here at least was no Stevenson. It was written as a 'weekly exercise': the week had been spent in diligent grubbing among parliamentary papers and statistical reports, and the matter was treated with a diffuseness which, after all, was not inappropriate. I think he liked my excuse (borrowed from Pascal's apology for the length of one of the Provincial Letters) that I had not had time to make it shorter. Anyhow, at the end of the session Jenkin surprised me by the offer of a place on the staff which he and Sir William Thomson were then forming as engineers of a great telegraphic enterprise, coupled with a promise that I should be released to continue my studies during the following winter. For a young man without influence or prospects this was an opportunity not to be missed. I went at once to London at their bidding, and set about learning how to make electrical tests in the cable factory, which at that date was a better school of electricity than any laboratory; returned to Edinburgh for a second session in the classes of Jenkin and Tait and Crum Brown; then again to London on the same mission, and from there later to South America—in three successive expeditions—to take part in the laying of cables along the coast of Brazil from the Amazon to the River Plate. This was in some sort an education, but it was not till 1876 that it became possible again to settle in Edinburgh and pick up the dropped threads of University life. From then till 1878, when on Jenkin's nomination I went as professor to Tokyo, I continued to work with him, mainly as assistant in various pieces of engineering and scientific research. Much of the work was done in his house, and one soon came to know the family, from 'Madam'—which in later years was Mrs. Jenkin's *nom d'amitié* to

all her intimates—down to Jack the terrier and Martin the cat. There were opportunities too of meeting the frequenters of the house, and of these the most remarkable—apart, of course, from Sir William Thomson—was Louis Stevenson.

To serve two such masters as Thomson and Jenkin was a privilege beyond estimation for a young man on the threshold of a scientific career. Thomson's genius was supreme; the better one came to know him the more one admired and loved him. With his greatness was mingled a beautiful simplicity, a modesty and consideration for others that made the doing of any service no less a pleasure than it was an honour. He was then President of the Royal Society of Edinburgh, an office which often brought him from the west. In these flying visits, besides attending to the interests of the Society, he had to meet as best he could two claims that were in sharp competition with one another. He was Jenkin's partner in practical concerns that involved big responsibilities and clamoured for attention. He was Tait's partner in the authorship of Thomson and Tait's *Natural Philosophy*—a gigantic infant that seemed always struggling to the birth. Hence between Jenkin and Tait there was strife for Thomson's soul. In point of fact Jenkin did all that could be done to relieve his partner of business detail. But in Tait's eyes Jenkin stood for a malign influence dragging Thomson to earth when he should have been free to soar and float in the serene air of mathematics, at a level where *Natural Philosophy* might forget that it had anything to do with the affairs of men.

IV

Into this firmament Stevenson from time to time would flash, erratic, luminous, arresting—a comet with

no calculable orbit or recognizable period—liable to disappear for months, but in my eyes, at least, a distinctly heavenly body. I was five years his junior, and between twenty-seven and twenty-two there is a great gulf. This, apart from other reasons, made it the business of the younger man to look up. Already Louis had the glamour of the successful author ; he was appreciated by *cognoscenti* though not yet popular. His essays and short stories were being taken by *Cornhill* and other magazines. I had sense enough genuinely to enjoy them. My admiration for the man of letters was real and ardent. But stronger than that was the attraction of his personality. There was a quality about his talk, his gestures, his smile, that was not only winning but extraordinarily stimulating and infectious. With other men—and women—you might be a pedant or a prig : with Stevenson you caught something of his careless gaiety. You were lightened, as a diver who had rid himself of his leaden boots. You might even then fail to come to the surface, and be only standing on your head, but at least you could kick out. You found yourself saying things that sounded almost good—things that made people laugh, apparently in good faith. It was very surprising, especially when one was young and not a little bashful. Next day the good things, and you, might seem dull enough ; but with his presence the magic would come back. The dust of forty-five years has covered what he said. The words, the wit, the essence are gone beyond any hope of recapture ; but the vision of the speaker does not wholly fade, the emotion of the moment can still, if faintly, be recalled.

I remember a sudden departure after one of the Jenkin plays. Stevenson was standing in the wings, ready to go on in the dress of a Greek Messenger which had been designed by Fleeming with a fidelity that excluded

pockets. Louis had omitted to divest himself of a signet-ring he usually wore. Handing it to me he said, 'Wear it till I come off'. We forgot it that night, and next day he vanished into space, it may have been to Grez or Barbizon. Months passed before the ring was reclaimed. I think the occasion of its return was a walk made memorable by his advising me to read Meredith. I had some acquaintance with *The Adventures of Harry Richmond*, having followed them with a schoolboy's eagerness as they came out in *Cornhill*. But I knew nothing of *The Ordeal of Richard Feverel* till Louis put it in my way. He spoke of the love story of Lucy and Richard with an enthusiasm I soon learnt to share. That must have been shortly before a visit to Burford Bridge brought him almost to Meredith's door, and he sought leave, as Sir Sidney Colvin tells,¹ 'sensitively and shyly, not without fear of a rebuff, to pay him the homage of a beginner to a master'. In our intercourse if there was shyness it was on my side, and Louis was kind in allaying it. The hours flew, but what their wings were one cannot now tell. There was some common ground between us in enjoyment of books; there were my sea travels and a few modest adventures on the South American coast—a shipwreck escaped, a revolution witnessed, an uncharted island passed close in the night and only discovered at dawn. We talked of the Jenkins: the affection we both had for them was link enough to establish a sort of brief intimacy. They were people too interesting, too unusual, not to be discussed by their friends from every possible angle of comment. He would tell me of some passage with Fleeming that had left him sore: there was no malice on either side, and only augmented admiration on his. The influence which Jenkin had exerted and was still exerting on him was

¹ *Memories and Notes* (1921), p. 167.

very apparent. For Stevenson in his turbulent youth, questioning everything and impatient of authority, nothing could have been more salutary than to find so lofty a standard of conduct, so clear and simple a philosophy of morals, in a man who was no puritan, who loved and understood him, who cared intensely for the things for which he cared, and whose zest in life was equal to his own.

The meetings I recall took place in 1877 and 1878, when Louis had passed what he himself set as the limit of youth, five-and-twenty. It was the period between the *Inland Voyage* and the *Travels with a Donkey*. Stevenson was then in what, for him, was excellent health; happy in the steady advance of his position as a writer; his purse still empty, but a little money beginning to come in; his pen very busy. He had qualified for Advocate, but his pursuit of the law had ended with the examination. So far as he was professionally concerned, the ancient House of the Scottish Parliament had again seen the end of an old song. He had shaken the dust of that *salle des pas perdus* from his feet. There was a brass plate bearing his name on the door in Heriot Row, but it brought no briefs and none were wanted. He was giving himself whole-heartedly to letters and thereby building a monument more enduring than any brass. 'I have a goad in my flesh continually,' he writes at that time to Mrs. Sitwell, 'pushing me to work, work, work. . . . I begin to have more hope in the story line, and that should improve my income anyway.' And to Colvin: 'I have been at home a fortnight this morning, and I have already written to the tune of forty-five *Cornhill* pages and upwards.' There was no need of any further apology for idling.

Among these slender memories one thing comes to me very clearly which may be worth recording. There

have been hints and innuendoes that in the young Louis high thinking went with loose living. Gossip is a lying jade ; the wise man learns to judge people as he finds them. On board ship and in visits to the cities of South America—Cities of the Plain they seemed to a youngster bred in a Scottish manse—I had rubbed shoulders with men who did not ride their appetites on the curb. It is a type not difficult to recognize. I was sensitive to it, and even in Victorian days the smoking-room was apt to become a sort of involuntary confessional. In Stevenson's company I never saw a trace of laxity—vinous or other—nor heard from him a word that might suggest it. His conversation, whenever and wherever we were together, alone or with other men, was as clean as his books. In such matters no evidence will prove a negative. This note of a direct personal impression is offered for what it is worth : so far as it goes it is evidence, not rumour.

V

My most frequent occasions of meeting him were at the Jenkins' private theatricals. By the time I came to know them these annual, or nearly annual, functions had become a great social event of the Edinburgh spring. The central figure of the plays was Mrs. Jenkin, whose genius—no lesser word will serve—was their motive and justification. In his wife's genius Fleeming took open pride and infinite enjoyment. His own talents shone as producer and manager. To select, adapt, and mount a play, to drill and dress his very capable company of amateurs, to design costumes and arrange accessories, gave scope to powers he loved to exercise. He threw himself into it all with characteristic energy and infectious enthusiasm, with meticulous attention to detail and a rare appreciation of stage effect. Each year there

were in general two plays, one following the other on the same evenings. The rehearsals went on daily for weeks, and finally there were five performances, two to audiences made up of artisans, servants, and dependants, and three to friends and social acquaintances. Plays were given from 1870 onwards in Jenkin's first Edinburgh house at 5 Fettes Row, and it was there that Stevenson joined the company. After 1873, when a Greek play had been presented for the first time—*The Frogs*, in Hookham Frere's translation—Jenkin moved to 3 Great Stuart Street, where a more elaborate setting became possible. There he engineered matters so that the end of the dining-room could be let down on hinges into the boys' play-room behind to form a stage, leaving all the dining-room area for auditorium. With various other devices in stage carpentry, this made a very perfect little theatre for performances which included versions, more or less curtailed, of *Twelfth Night*, *Antony and Cleopatra*, *The Merry Wives*, *The Rivals*, translations of the *Trachiniae*, the *Agamemnon*, and the *Andromache*; and also some lighter pieces. *The Taming of the Shrew* as well as *The Frogs* had been given in Fettes Row. For the first Greek play the dresses had been furnished by a theatrical costumier 'with unforgettable results of comicality and indecorum' (so says Louis). For the next Jenkin had dresses made to his own designs, having in the meantime discovered for himself how the Greeks did their tailoring—a discovery which he made partly by experiments 'with sheets and lay-figures, and later with shawls and real women', and partly by studying sculptures in the British Museum. I cannot say whether his theories of the *chiton* and *diplois* and *peplos* were sound: in any case the results were extremely graceful, and certainly decent.

Of Mrs. Jenkin's range and power in dramatic inter-

pretation a vivid impression remains, but an impression difficult in any measure to convey. One felt, and feels, certain that had she sought fame on the professional stage she would have found it given without stint. She was delightful in comedy, but it was in the simple cumulative tragedy of the Greeks that she was at her greatest. To see her then was to be profoundly moved : it was also to be allowed a glimpse into what Greek drama really is, into the secret of its perpetual appeal. Let me quote the opinion of two authorities much more competent to speak than I. Sir Sidney Colvin, in the chapter of his *Memories and Notes* which is devoted to 'Fleeming and Anne Jenkin', says : 'Those of us who had the privilege of seeing and hearing her will never forget the experience. . . . To hear her declaim dramatic verse was to enjoy that art in its very perfection. And her gift of dramatic gesture was not less striking. Recalling her, for instance, in the part of Clytemnestra, I can vouch for having seen on no stage anything of greater—on the English stage nothing of equal—power and distinction.' And Louis has written : 'As for Mrs. Jenkin, it was for her that the rest of us existed and were forgiven.'

During the dozen years or so in which plays were given the company underwent many changes. Among its members when I knew it, besides the Jenkin family and Louis Stevenson, were Mrs. Jenkin's mother, Mrs. Alfred Austin, whose refined dignity showed to advantage in various elderly parts, Miss Leila Scot-Skirving, Miss May Cunningham, Miss Ella Cay, Miss Lee, Miss Paton, Mr. W. B. Hole, Mr. Orme Masson, Mr. Jules Kunz, Mr. H. Blackburn, Mr. A. Burnett, and others. Hole, then becoming known as an artist (his fame as an etcher came later), was very good on the stage—where he took himself seriously—and still better in the supper-room after the play, where he would sometimes delight us by giving

free rein to his talent as a low comedian. No one who saw it will have forgotten his impersonation of the absent-minded entomologist who let one of his live specimens escape. Stevenson was no more than a fair actor. The parts assigned to him were as a rule of secondary importance ; but off the stage, in the merry nightly gathering that followed rehearsal or performance, he took a recognized lead, bubbling over with inspired nonsense. He began, I think, as prompter, in 1871. Next year he figured as an 'inarticulate recipient' of Petruchio's whip in *The Taming of the Shrew*. By 1873 he was promoted to the part of Vatel, a cook, in *My Son-in-Law*, a translation of *Le Gendre de M. Poirier*, and to that of Aeschylus in a curtailed version of *The Frogs*. In 1875 he was the Duke in *Twelfth Night*, and it was then he wrote to Mrs. Sitwell :

'I play Orsino every day, in all the pomp of Solomon—splendid Francis-the-First clothes, heavy with gold and stage jewellery. I play it ill enough, I believe ; but me and the clothes, and the wedding wherewith the clothes and me are reconciled, produce every night a thrill of admiration. Our cook told my mother (there's a servants' night, you know) that she and the housemaid were "just prood to be able to say it was oor young gentleman". To sup afterwards with these clothes on, and a wonderful lot of gaiety and Shakespearean jokes about the table, is something to live for.'

But Louis did not tell how very literally he obeyed on that occasion his own opening injunction to 'play on'. At supper, when all was over—so runs the tradition in the Jenkin family—he continued to personate Orsino in a superbly ducal manner, improvising lines which Shakespeare might have mistaken for his own.

In 1877, when it was my privilege to join the company in the invisible rôles of call-boy and property-man, the

chief play was *Deianira*—the name given by Lewis Campbell to the first part of his translation of the *Trachiniae* of Sophocles. Mrs. Jenkin, of course, played Deianira. Her presentation of the wronged wife, led into fatal error by her wounded love, held every audience enthralled, and bore out Lewis Campbell's remark that there is no play which more directly pierces to the very heart of humanity. As produced, the play ended with the announcement by the Nurse (Mrs. Austin) of the death of Deianira; our sympathies were not distracted by the final appearance of Heracles in his last agony.

Deianira was followed, for a lighter course, by *Art and Nature*, which was an adapted version of Charles Reade's *Masks and Faces*. Mrs. Jenkin passed with consummate art from the stricken house of Heracles to the Green Room of the Theatre Royal, Covent Garden, where she became the flippant, kind-hearted Peg Woffington. Stevenson was the Messenger in the Greek play; he had a more considerable part in the comedy as Sir Charles Pomander. Of his performance on the stage I can recall little, save that as the officious old messenger he sustained with spirit an altercation with Lychas (Mr. Hole), in which, after much bluffing, Lychas is forced to admit the truth about the captive Iole. But there was an awful moment, entirely unrehearsed, when the 'streak of Puck' that was in Louis got the better of him and he raised the curtain on a scene not in the play. That story should be told—I hope will be told—by one who saw the scene from the front. It was a chastened Puck who emerged, some minutes later, from a private interview with the manager.¹

¹ The story has been told as follows by one who saw the scene from the front, Miss Flora Masson, in her book *Victorians All*:

'The curtain had fallen on a powerful and moving scene, amid the applause of the audience, and the stage was left in the possession of two of the young actors—Mr. Hole and my brother—both in Greek

My duties, which were many, required me to procure each night from the kitchen a practicable and really eatable pie for consumption by the family of Triplet; and also to disturb at necessary intervals, always discreetly and at the last minute, various promising flirtations on the stairs. They did not debar me from a full and lively enjoyment of what Louis has described as 'a long and exciting holiday in mirthful company'. But they were no sinecure when, in the late autumn of the same year, the *Deianira* was repeated in St. Andrews, with nearly all the original company and stage effects. The stage had to be erected in the Town Hall there, the scenery and properties transferred, down to 'the wig which Stevenson wore, a venerable, straight-haired white

garb. In a momentary reaction after so much unrelieved tragedy, these two, oblivious of their classic draperies, threw themselves into one another's arms, performed a rapid war-dance, and then flung themselves on to opposite ends of a couch at the back of the stage, with their feet meeting in a kind of triumphal arch in the centre. Louis Stevenson, who had been officiating at the curtain, took one look at them. He touched a spring—and up went the curtain again.

'The audience, scarcely recovered from the tragic scene on which the curtain had fallen, gave one gasp of amazement, and then broke into a roar of applause. That roar was the first thing that showed the two luckless acrobats that something had happened. They leapt to their feet—only to see the curtain fall once more. Professor Jenkin, who was host and stage-manager in one, had been watching this particular portion of the play from the front. Without a word he left his seat and went behind the scenes. "Mr. Stevenson," he said, with icy distinctness, "I shall ask you to give me a few minutes in my own room."

'Anybody who ever saw Louis Stevenson can imagine the little enigmatic flutter of a smile, the deprecatory bend of the head, with which he followed the Professor. What happened in that stage-manager's room? There was some trepidation among the members of the company and a furtive whisper circulated: "*Can it be corporal punishment?*" And there was a general feeling of relief when Louis sauntered into the drawing-room with a look of absolute unconcern.

'But one of the little company—the brilliant, charming, irrepressible Leila Scot-Skirving—was interested enough to linger behind the others and to waylay Louis as he left the Professor's room. "What happened?" she whispered; and Louis whispered back: "The very worst ten minutes I ever experienced in the whole course of my life!"'

wig' (so my list has it)—and all this before the return of Jenkin at the eleventh hour from his Highland holiday.

That was the last occasion on which Stevenson actually took part in the plays.¹ In 1878 there were none. There were, however, great doings at a Bazaar for the University Cricket Ground, when we exhibited the phonograph for the first time in Britain—having made one for the purpose by help of a notice of Edison's invention which had been cabled to the *Times*. People crowded to see and hear the strange new thing. We applied it afterwards in researches on the nature of spoken sounds—a work which took up much of Jenkin's time and mine, but with which Stevenson and other members of the Jenkin circle had only casual connection, as supplying records for analysis. For the moment they were all *voces et praeterea nihil*.

People who know only the very perfect gramophone of to-day can have little idea of the weirdness of its first parent, the phonograph of 1878. It recorded sounds by making little indentations on a sheet of tinfoil, wrapped tightly round a grooved brass cylinder, which was slowly turned by hand while the speaking went on. It was an immensely entertaining toy. The turning by hand was usually rather irregular, so the reproduction of song was a travesty, and that of speech seemed to emphasize all the least agreeable peculiarities of the speaker's voice. To hear oneself as others heard one—in the phonograph's interpretation—was a shock to the most complacent vanity.

In the early summer Jenkin went to Paris to act as juror in the Exhibition, taking Stevenson with him as secretary. I had many letters from Jenkin in Paris,

¹ There is a small error in Sir Graham Balfour's Life (vol. i, p. 121) where it is said that it was in 1875 Louis last took part in the Jenkin theatricals. He had parts in both of the plays in 1877.

but none were written by the secretary. Later in that year I went to Japan and saw Louis no more. In 1879 the sequence of plays was resumed with *Antony and Cleopatra*, concerning which Jenkin wrote to me in October as follows :

' I suppose we sent you playbills of *Antony and Cleopatra*, but on my word I do not remember what we did or did not write. It was marvellously successful against all the predictions of our company. Never, never, did I see a more amusing sight than the faces of the company when they were told what the play was to be and which parts they were to have. I read the play as curtailed and arranged to the gloomiest audience ever collected. Hole and Louis Stevenson got up a little conspiracy to get it thrown over, because, as they said, the part was not good enough for Mrs. Jenkin. This is a little condensed but not exaggerated. Then Hole thought Enobarbus was not a part. Then another most daring idea was letting Lewis Campbell, who had never acted in his life, take Antony. This was atrociously bold, but we had heard him read Shylock so well that we decided he was our best chance, and he at least was partly happy, but all his friends explained to him that he was a perfect idiot to try, and that in fact he was making an old fool of himself, so his pleasure was not unalloyed. Then twenty-eight people were required in all, and all their dresses had to be designed and arranged, and of course they all thought they would be guys. And when Hole first appeared he certainly *was*, and he was furious when I told him the dress was very unbecoming, although he had himself told me it was horrible. However I polished him up till he was quite beautiful and strutted with enormous satisfaction to himself and with the approval of the house. Indeed I got all the men to look very well, which is difficult with classical costume. I went for bare knees and arms *à la* Highlander. This made an immense difference from the usual stage Roman. Then I gave

them all long handsome buff boots laced up the front (as high as a Highlander's stocking). This looked noble, and with the properly cut tunics *à la* Alma Tadema, and tremendous Saga (or military cloaks), swords, belts, helmets, and so forth, it was gorgeous, and they all felt it so, and held up their heads instead of sneaking about like supernumeraries. Mrs. Jenkin was incredibly fine : it is of no use trying to describe it. The fifth Act and the end of the fourth were the finest things she has done yet. The scene where the messenger brings the news from Rome of Antony's marriage was the one which each night secured the success of the play—Scene v, Act ii. Up to that time people were pleased and, to their own amazement, interested, but this scene was something for which they were so wholly unprepared that the excitement became tremendous. Cleopatra was swathed in a sort of huge shawl of dusky purple and had on an Egyptian-looking head-dress of Cretan embroidery. Her dash at the messenger was one of the finest things in athletics you ever saw : it fairly frightened people, let alone Mr. M. C. Smith himself, who, however, got used to it—but for rage you never saw anything like it. Then the banqueting scene acted uncommonly well. Kunz was an admirable Lepidus and young Charles Hallard sang the song to a good old tune found by Hole. It made both a lively and a most picturesque scene. Lewis Campbell was better than any one else we could have had as Antony and acted with great fire. He was not, however, very successful with the audience. It would be a long business to analyse the why. However, he in no way spoilt the play, and any one else we could command would have done so. All my twenty-eight came round (except Louis Stevenson, who was ill and had to go away and never saw it), and in the end I never had so enthusiastic a company. At the supper Hole made me the sweetest speech, thanking me for having made him successful at last, and we were all extremely happy. Your part was taken by five people—one to each Act—

but the five were not worth you. . . . Austin [his eldest son] did a small part extremely well. We do not see that anything in the world is left for us to do now.'

However, they did find something, for next year (May 1880) he wrote to me of the *Agamemnon*, in which Mrs. Jenkin took the two parts Cassandra and Clytemnestra :

' Our plays are successfully over. Mrs. Jenkin surpassed herself. The Cassandra was more popular than the Clytemnestra—beauty being more appreciated than the rather objectionable power of the murdering woman. I had a triumph too in being able to show some learned friends that a dress-rehearsal audience of artisans and servants could be powerfully moved by a Greek play. Scholars have a way of thinking these productions beautiful but dull, and are almost insulted when told that any one but a scholar can admire them, whereas often the scholar has never seen at all what is most admirable in them—the human nature. Austin came out with extraordinary vigour. His mother's talent is now showing in him and he did much of the impossible part of the First Citizen quite admirably. . . . I have acquired the art of beard-making from an ancient Jew supporter of the house of Nathan. I am a very promising pupil of his.'

And in November :

' We repeated the *Agamemnon* in London before some very distinguished audiences and had a great success. (Most of my actors new there.)'

In 1882 the play was *Griselda*, one written by himself, which was afterwards published among his *Collected Papers*. In December he wrote to me again :

' I am desperately busy over *Telpherage*. . . . Also we are getting up plays : the *Andromache* and the *Merry Wives*, much cut down.'

Finally, in January 1884 (the year before Jenkin

died), they gave De Musset's *May Night and October Night*, along with scenes from *The Rivals* and a revival, after an interval of thirteen years, of *La joie fait peur*, in which the Professor played the part of an old servant 'most beautifully'. In July of that year I remember going with him in London to see a trial matinée of *Deacon Brodie*. We sat beside Bob Stevenson. Louis was not there, but Henley hobbled on to the stage to take the call. The play had no more than a *succès d'estime*.

Let no one suppose, from the prominence given to the plays in these notes, that such *parerga* took Jenkin's attention away from more serious matters. All the while he was carrying on a busy professional life, teaching, inventing, writing, researching, preaching a gospel of sanitary houses, steering with conspicuous success a rich argosy of patents past the rocks and shallows of possible infringement and litigation. The letter that told me about the *Agamemnon* contains the following passage :

'Thanks for the congratulations on the Keith Medal and for your opinion on the paper.¹ I took the medal with a good conscience, for I confess to being proud of that paper. I have just done, all but the index, a little book on Electricity. The bigger one has now been translated into German as well as Italian. A French edition is coming out too,—all which makes me wish I had taken more pains with the original, especially in arrangement and wording. You will be amused to hear that with Jameson's assistance I still potter on at the old heat-engine. . . .'

The letter goes on to discuss experiments and cable business.

¹ A highly original paper on Applications of Graphic Methods (reprinted in his *Collected Papers*, vol. ii), which received the Keith Gold Medal of the Royal Society of Edinburgh for the period 1877-9.

The last meeting with Louis that I recollect was in the summer of 1878, when Jenkin asked us both to dinner to meet Mr. Taiso Masaki, a Japanese official who had come to Edinburgh in search of a professor for the University of Tokyo and had swept me into his net. Mr. Masaki told us the story of an early hero of the Japanese renaissance—Yoshida Torajiro—a story of patriotism and adventure, of sustained struggle and frustrated hopes. Louis was deeply stirred. He made some notes, got Mr. Masaki to supplement them later, and finally wrote the story out as no one but he could have done. He tells there how the young Yoshida, when in prison and soon to be led to execution, took heart on hearing the words of the classic poem :

It is better to be a crystal and be broken,
Than to remain perfect as a tile upon the housetop.

Did these words, I wonder, appeal to Stevenson as a motto which might have application to his own short life ?

THE STEVENSON MEMORIAL, EDINBURGH

IN opening the house at 8 Howard Place, Edinburgh, in which Robert Louis Stevenson was born, as a permanent memorial and museum (June 9, 1926), Sir Alfred Ewing said that though the Memorial House was Stevenson's birthplace, it was not there that he learnt to be a man of letters. For he left Howard Place at the age of two and a half. But they might fancy it was perhaps on those stairs that the lengthening and crooked shadows marched along—the shadows which went 'tramp, tramp, tramp'—while Alison Cunningham carried the candle and led the child to bed. It was just possible, for Stevenson must have been a rarely observant child.

The Stevenson Club were to be congratulated on the restoration and arrangement of the house. It was incumbent on any lover of Stevenson, who had it in his power, to contribute to that collection of relics—tangible objects which served, on the material side, much the same purpose as Miss Rosaline Masson's gathered reminiscences served in other ways. Here, as in her book, were gathered a number of miscellaneous fragments, heterogeneous, unequal, some more important than others, but none entirely unimportant or unworthy, and surely all gaining by the fact of their juxtaposition. In both cases it might truly be said, a little longer and all would have been lost.

Apart from his admitted place in the world of letters,

Stevenson intrigued them as a human being, who shared the frailties of our bodily and spiritual frame. He had notably the gift of inspiring affection in his readers. One was always conscious of the man behind the writer. Beyond the immortal, one discerned the elusive, weak, wayward, lovable mortal, struggling against the handicap of illness and the sins which so beset him, sometimes backsliding, but at length in great measure triumphing. Few, if any, of the masters in literature compelled so wide, so intimate an affection. One saw him, in his youth, a figure of revolt and misrule, intolerant of conventions, striving for a liberty he had not yet learnt to use. He was a bundle of contradictions, where a careless gaiety, a gentle playfulness, and much sweetness of nature did not exclude an angry and almost defiant criticism of life. The importunity of the senses was at war with instinctive morality and even religion. One saw him later in his much more serene maturity. As life went on, it was the better part of him that won the day, and they might be said to love him all the more for the early turbulence which passed into serenity. It was a life that provided curious material for the scalpel of the biographer.

XII

ODDS AND ENDS

THE ENGLISH SHARE IN PHYSICAL SCIENCE

AN ARTICLE IN THE *EVENING NEWS*, JULY 20, 1928

IN a recent lecture to a centenary assembly at the Institution of Civil Engineers,¹ I had occasion to review the progress of physical science during the past hundred years, so far as it bore on engineering. I pointed out that in this field we advance in two ways. As the outlook of mankind becomes more systematically scientific there is a steady modifying pressure which incidentally improves the processes of the engineer. But besides that, there is from time to time the birth of a new idea. The scientific intuition of some man of genius causes a break away from former tradition and habit. A fresh method, such as the Bessemer process of making steel, or a novel appliance such as the steam turbine, comes into being, wholly different from what has been in use before. This occurs unexpectedly, like what biologists call a sport. Thereafter the current of steady progress follows a changed course. The same distinction holds in the history of science itself as well as in its applications. A Newton, a Dalton, a Faraday, a Clerk Maxwell, a J. J. Thomson turns the stream of discovery into a channel where it irrigates some previously infertile soil, just as a Watt or a Parsons gives

¹ See page 29 of this volume.

the world a device which opens up a vista of further invention and, in new ways, harnesses nature for the service of man.

Throughout all this march of discovery and application, England (I use the word in its widest sense) has been, and still is, a leader. Historically and actually the British share is bigger than the layman is apt to realize. He has every excuse if he does not know what is going on. The Proceedings of learned societies are stodgy : even an expert's interest is restricted to items which at the moment concern him. Discoverers are seldom good expositors ; moreover, they are usually very modest about what they have done. But if the layman imagines that other nations have outstripped England in the race, he is definitely wrong.

Not least of the glories of science is that it ignores nationality. No country has a monopoly of discovery : few if any cannot point to epoch-making contributions. Science advances on so wide a front that there is room for many in the van. To claim credit for one nation implies no disparagement of others. But the British instinct towards self-depreciation is curiously misapplied if it makes people think poorly of our past or our present in the world of the physicist and the engineer.

Everybody knows that in the middle of last century new foundations were laid in biology by the teaching of Darwin. No less fundamental a change took place in the science of non-living matter ; the mechanical theory of heat revolutionized physics and engineering. That revolution was mainly the work of English physicists. Joule of Manchester showed that heat and work were interconvertible, and found by experiment the mechanical equivalent of heat. William Thomson, afterwards Lord Kelvin, extended the new ideas into all regions of physics, formulating the science of thermodynamics on

lines as comprehensive as they have proved enduring. He gave us the absolute scale of temperature and the doctrine of the dissipation of energy. His grasp and insight, with his instinct for practical application (deep-sea telegraphy was only one among his many inventions), made him the most forceful leader of what was then a new era. Rankine, Professor of Engineering in Glasgow, was the first to develop the theory of steam engines. Another giant of the period was Clerk Maxwell, first head of the Cavendish Laboratory at Cambridge, who gave us the molecular theory of gases, and recognized the correspondence between electrical oscillations and the waves which constitute light. Other outstanding leaders were Rayleigh and Crookes. Rayleigh, among various great services, detected the presence in the atmosphere of a hidden constituent which is now called argon. Ramsay splendidly followed up that first step by separating four other members of a new family of elements—helium, neon, krypton, and xenon. These gases, inert and rare, have found unexpected uses, but their greatest value is philosophical: they fill essential places in the periodic series which reveals itself among the atoms as we pass up from the lightest element to the heaviest. Crookes was a pioneer worker on the electrical discharge in highly rarefied gases, discovering what he rightly called a new state of matter. His cathode rays prepared the way for J. J. Thomson, whose identification of the electron as a separate entity may be called the beginning of what is still the new physics. All J. J. Thomson's work, and that of the brilliant school he founded, has been a triumphal march. His most eminent disciple is Rutherford, successor to him in the Cambridge Chair, discoverer of radium-emission, and chief author (along with the great Dane, Bohr, who in his turn was a pupil of Rutherford) of the modern conception of the atom as a com-

plex and immensely open group of particles of electricity. Others of the same school were C. T. R. Wilson, who exhibited the tracks and impacts of atomic fragments ; Barkla, who showed that every kind of matter gives out its own characteristic rays ; Aston, who, by his study of isotopes, has proved that all atoms are built out of one and the same type of brick-bat ; O. W. Richardson, whose examination of the emission of electrons by hot bodies has been fundamental in the subject to which he has given the name of thermionics ; and Moseley, a victim of the war whose early death did not prevent him from leaving an imperishable monument through his discovery of the real meaning of atomic number in the list of elements. Soddy, working with Ramsay, first gave proof that helium is formed by disintegration of the atom of radium. To the Braggs, father and son, we owe the optical analysis of crystal structure, superbly applied to elements and compounds. To Fleming we owe the thermionic valve, which more than any other appliance has made broadcasting possible. To Dewar we owe the vacuum vessel and much initial work in the liquefaction of gases. To Hadfield and other British metallurgists are due notable advances in the alloys of iron and the working of metals.

Jeans and Eddington lead the world in mathematical astronomy. Their imagination fits them to be historians of the cosmos : they interpret universes in the making : they describe with unrivalled lucidity events that transcend time and space. Here indeed the discoverer is also the witty and charming expositor. The same is true of Oliver Lodge, whose part in advancing physics has been very real, though he sometimes strays into regions where more orthodox explorers do not follow. We are fond as well as proud of one who, besides being the Nestor of physics, is its Peter Pan.

In a more practical sphere it was William Froude and Osborne Reynolds who gave to shipbuilding the science of the experimental tank, studied stream-line flow, and established principles now fundamental in aviation. It was John Hopkinson who pointed the way to rational design in the dynamo. And it was Charles Parsons who not only invented the steam turbine but devoted himself, with no less tenacity than genius, to improve and apply it on sea and land until it became the greatest means of producing and distributing power.

These are only a few items drawn from a field within my own observation, instancing the work of men nearly all of whom I have known. I do not doubt that in other branches of science a like claim may properly be made. It happens that of those named here no fewer than nine have been awarded the Nobel Prize, a mark of international distinction which shows there is nothing parochial about their fame. To do justice to such a subject would take much space; enough has perhaps been said to make it clear that Britain does not lag—that the early fathers of English science have bred worthy sons.

SPEECH AT THE ANNIVERSARY DINNER OF THE ROYAL SOCIETY, IN REPLY TO THE TOAST OF 'THE MEDALLISTS', NOVEMBER 30, 1895

WHEN asked to reply to this toast, I was told that the selected medallist¹ usually gives a short biography of each of his colleagues, with a critical synopsis of their works. If this be the established practice, I hope you will allow

¹ The other medallists were Dr. Karl Weierstrass, Sir John Murray (of the *Challenger*), and Sir William Ramsay. The Chairman was Lord Lister (then Sir Joseph), who had that day succeeded Lord Kelvin as President of the Society.

me to depart from it. Of Dr. Karl Weierstrass any word of eulogy would be presumptuous. The pure mathematician stands on what to me and to most of us are inaccessible heights : he breathes a rarer air than will serve the dweller on the plains. We are content to know that Dr. Weierstrass is teacher of the teachers of Germany, and is hailed as master by such as are qualified to judge. This year has bereft England of her greatest mathematician through the death of Cayley : to the student of mathematics there will be some consolation in seeing the Copley Medal—the highest honour the Royal Society can bestow—conferred on his famous foreign colleague.

Turning now to the other medallists, I am on more familiar ground. My foot is on my native heath. If one of the medals has gone to Germany, the other three have come to Scotland. This is said in no spirit of provincial boasting, but in gratitude to the Society for its tolerance of such an invasion by the Celtic fringe. The expression about one's native heath is not to be taken too literally : I am afraid we all three, in our several ways, illustrate a recognized tendency on the part of the Scottish foot to tread southern heather.

You will admit that there is nothing provincial about the work of John Murray. The world has been his oyster. He has dredged for it, he has opened it, he has dissected the contents and studied the shell—all with such assiduity that few naturalists have libraries large enough to contain the books he has edited or written. I remember how in Tait's laboratory at Edinburgh, where he and I as babes together drank the sincere milk of natural philosophy, the news one day went round that John Murray was appointed to the *Challenger*. Later I came on his tracks in Japan, where he had been teaching that receptive people to lisp such phrases as 'globigerina ooze'. Through the death of Wyville Thomson the mantle of Elijah was to fall, all too

soon, upon Elisha ; but he was equal to it, and you have heard to-day of the splendid service he has rendered to Zoology. The Expedition of the *Challenger* was a long chapter in the romance of science. To find a parallel in the past we should go back to the voyage of Æsculapius in the company of Jason.

And if Murray's work has been romantic, may we not say the same of the discoveries of Ramsay ? It is the business of science to suggest a common type-name under which individuals may be grouped. I find a title equally applicable to Murray and to Ramsay in the name given to Jason's crew : both alike are Argonauts. If it has not been Ramsay's lot to sail distant seas, he has at least travelled as far as the Embassy of the United States, where with Lord Rayleigh he was invested with a Smithsonian Golden Fleece for his share in isolating argon. In one of Poe's tales, which were the delight of my boyhood, a story is told of how a compromising document was successfully concealed by the expedient of putting it in the most conspicuous possible place. That has been Nature's method with regard to argon. We have breathed it every moment of our lives, as M. Jourdain talked prose, without suspecting the fact. Rayleigh and Ramsay have discerned that to which other chemists were blind. The Argus eye is one thing, but the argon eye is quite another.

Of the remaining medallist there is little to be said, save that he is profoundly conscious of the honour done him in the gift of a Royal Medal. One ought perhaps to say 'medals', for it is pleasant to discover that whatever the economic doctrine of the Royal Society may be, in practice it is Bimetallist. It has been suggested that one of the medals is designed as a reserve, which will allow the other to go into circulation. But I prefer to read in the double gift a hint to your after-dinner speakers, that while speech

may sometimes be silvern, it should never stray far from the silence that is golden.

May I, however, take time to recall how in those early days of student life at Edinburgh it was my privilege to hear you, Sir Joseph Lister, make a communication to the Royal Society there which, as we are now aware, marked an epoch in surgery ? To illustrate your novel practice you had brought to the meeting a flask of milk which you had yourself drawn from the cow, some months before, under the antiseptic conditions you originated. You held up the flask, and without a moment's hesitation withdrew the stopper and drank the contents, not turning a hair. We youngsters gazed at you, as the barbarians of Malta gazed at St. Paul when a viper bit him, expecting you would presently develop symptoms of internal distress. It was a disappointment that nothing seemed to ruffle your serenity. But we came later to know that in your demonstration we had witnessed the making of scientific history ; and since then you have had the noble happiness of seeing a generation of the suffering rise from their sick-beds to call you blessed.

If anything could add to my pleasure in receiving a medal it is the fact that I took it from the hands of my revered master, Lord Kelvin, the object of my earliest scientific worship. It was through reading, when a boy of fifteen, an article on the Conservation of Energy which bore the signatures of Thomson and Tait, that I realized a bent towards physical inquiry. Soon afterwards, in Tait's lecture-room, I learnt to venerate the name of Thomson, and a little later I had the joy of entering his service. It too often happens when we reach the comfortable latitude of forty that we find the old gods' altars untended and the fires upon them grown cold. That has not been my experience. This is not the place or the time to speak of the debt that every student of physics owes

Lord Kelvin. But mine is a more personal obligation. Perhaps you can conceive what his notice and approval meant to a novice ; what his sympathy and criticism have meant throughout my life. I am more than ever the pupil and servant of one whom all men admire, whom those who know his works reverence, whom those who know himself also love.

ADDRESS AS PRESIDENT OF THE ROYAL SOCIETY OF
EDINBURGH TO H.R.H. THE PRINCE OF WALES, ON
ADMITTING HIM AN HONORARY FELLOW OF THE
SOCIETY, DECEMBER 3, 1924

IN asking your Royal Highness to accept the Honorary Fellowship of this Society, we follow an ancient tradition which closely connects the Society with the Royal House. It is an election that does not impose or imply any scientific test. We exact no immediate contribution from you to the weighty contents of our published *Proceedings* or *Transactions*. But I do not forget that in an earlier stage of your Royal Highness's career, it fell to me to superintend an examination in scientific and other knowledge which you passed with a degree of credit that entirely satisfied the examiners. It is not on that ordeal, however, that your right to admission here is founded. It might indeed be rash to assume that you have retained all you then knew. Nevertheless I venture to assert that no one can challenge the fitness for our Fellowship of one who has already done so much to advance the interests which our Society has at heart. There are few, if any, travellers whose journeys take so wide a sweep as yours ; few if any ethnologists and sociologists whose understanding of peoples and their

modes of life and thought is so comprehensive. And I would wish, Sir, as a charmed student of your speeches, that you would communicate to us, if not the results of your researches, at least something of your power of terse and apposite expression—your happy knack of choosing and placing the nail and then hitting it on the head.

Though the Society is not neglectful of the claims of letters—and has numbered among its Presidents a literary star of the first magnitude—its main concern is with science. It was here that Lord Kelvin, who for many years held the same office, first made public some of his greatest discoveries. To you, Sir, these must specially appeal in one of their practical aspects, as having made it possible to link up, in a network of nearly instantaneous communication, the mother country with the most distant of the Dominions—Dominions which are now proud to hail you as their collective Agent General.

Your Royal Highness does not need to be reminded that it is to science and the applications of science that the Empire owes in great part its security and prosperity : that alike in peace and war, in nearly all the processes of life and conduct, science tends daily to take a more and more dominant place. In science too we have a world-wide interest, a common bond among all nations, a meeting-ground for agreement aloof from some at least of the differences that afflict and disturb in other spheres of thought. To these usually serene heights we now bid your Royal Highness welcome ; and accordingly, in the name and by the authority of the Royal Society of Edinburgh, I admit you an Honorary Fellow thereof, and ask you to subscribe the roll.

SPEECH TO THE 'WORLD FEDERATION OF EDUCATION AUTHORITIES'. FIRST BIENNIAL CONFERENCE: AT EDINBURGH, JULY 20, 1925

IN greeting an assembly such as this, it is natural to tell them that, when they come to Edinburgh, they have come to the Mecca of their subject. A few weeks ago I welcomed an incursion of some hundreds of American doctors to Edinburgh as the Mecca of Medicine. Their own leader was going to say the same thing, but fortunately I got it in first. To you one may, with equal truth, call Edinburgh the Mecca of Education. I am told that pilgrims to the real Mecca suffer all manner of discomfort in transport and accommodation, not to speak of the minor horrors of pilgrimage, but treat it lightly because they are buoyed up by two sentiments, their devotion to an ideal, and their enjoyment of the adventure of travel. If you require them you have the same two consolations: you are idealists in a great and worthy cause; and you have come to a city where it is easy to escape from the tedium of the conference room into surroundings that are rich in beauty and historical interest, and are potent in the stimulus of their romance.

It is inspiring to address such a concourse of men and women, drawn together by a common enthusiasm, experts in the same noble profession. It is inspiring also to think that behind the visible audience there is another, not in the same sense expert, but composed of persons to whom the subject has just as real an interest as it has to ourselves: a widespread audience of fathers, mothers, sons, daughters, to whom education is part of the daily problem of life. There is no time to say more than a few words to you and to them. What little I can say is said from the standpoint of one who has given the best

part of his life to the business of educating others, and incidentally himself.

My experience has been in what is called the higher education—a type of education which cannot and should not be general. To try making it so would be futile ; it would also be injurious to the interests of the community as well as those of the individual. The higher education ought, at every stage, to be selective, to be continued by the few who are fit to receive it with profit. What *should* be made general in this connection is opportunity. We must see to it that no person really worthy of the privilege shall miss his chance of the highest education. One of the functions of the primary and secondary schools is to discover the highly capable few and send them on to the Universities, whose doors must be kept open for them. No limit should be set to the advance of any youth with exceptional mental gifts. To provide such persons with the means of exercising their faculty for learning and research is a duty which the nation owes to them and to itself. They are a national asset which it would be folly to neglect ; and they are all the more valuable because they are uncommon. This is obvious of the greatest—the Shakespeares, the Newtons, the Faradays, the Kelvins. It is less obvious but hardly less true of many more whose natural talents are exceptional, though they fall short of genius. It is on such potentialities that we should concentrate our effort in this matter : attempts to make mediocrity keep pace with distinction fail dismally and expensively : they keep back those whom we should help to forge ahead and they are a disservice to those who should be left behind. Thanks to bursaries and grants, opportunity for the fit is now offered widely : it may require further expansion. But it should be associated with more careful sifting. One finds, as things are, that some

persons are brought into the procession who have no business to be there. The system as it stands is not free from inefficiency and waste.

My other word is this; have faith in education but do not expect too much from it. Those who look to it to make a new heaven and a new earth will be disappointed. It cannot be trusted even to make the present world safe for democracy, or democracy safe for the world. It offers no guarantee of right thinking. Not infrequently the educated man is wrong, and the instinct of the crowd knows him to be wrong. 'High-brow'—'intellectual', these are not names expressive of unquestioning faith in accepted leaders. They imply a criticism which is sometimes well deserved.

It is not for us, who believe in education, to overpraise it. I have sounded a warning note: I have suggested limitations, trusting that you will not misunderstand me. To you and to me, and to all who have seriously considered what education is, and know what it can do, it remains a thing worthy of our love and our endeavour, a force of incalculable possibility for the betterment of mankind.

SPEECH AT THE MODERATOR'S RECEPTION IN THE ASSEMBLY HALL, EDINBURGH, MAY 22, 1923

IT is a novel experience to find myself sandwiched as a speaker between two Moderators—to be, as it were, a grain (perhaps not wholly free of chaff) between the upper and the nether millstone. I imagine there may be moments in the life of a Moderator when he is oppressed with the burden of office, when he realizes that the verdict of his fellow-churchmen means nothing less than

a sentence of twelve months' hard labour. At such moments, or in anticipation of them, it is well for his friends to rally round and assure him how confident they are that he is worthy of the honour the Church has conferred.

I was trying the other day to explain to an Englishman what we in Scotland mean by a Moderator, and to put it simply, I said he was a sort of super-bishop, democratically chosen to hold office for a year. A well-known passage in the first letter of St. Paul to Timothy gives a list of the habits and qualities to be looked for in a bishop. It will not be disputed that the same tests might fitly be applied to a Moderator. There is as much need that he should be the husband of one wife, sober, no striker, given to hospitality, apt to teach, and so on. You know the list. But it is incomplete : if we may judge by the recent practice of this Church, there is yet another qualification which at least receives preferential treatment. It is surely more than a coincidence that six successive Moderators, Dr. Cairns and his five predecessors, are all sons of the manse. Dean Inge, in one of his essays, tells a story of an Eton boy who was asked why the sons of Eli turned out badly. The reply was that clergymen's sons always turn out badly. I, too, am a son of the manse, and so come under this condemnation. But putting myself on one side, I would ask you to look at the six Moderators and admit that they have avoided some of the faults which disfigured the careers of Hophni and Phinehas. To spare their blushes I shall put it no higher than that.

In all seriousness I for one can never be sufficiently grateful that I was born and bred in a Scottish manse. It was an atmosphere of frugality but never of penury, of thrift but never of meanness, of industry without monotony, of simplicity without dullness, of refinement

without affectation, of gentle culture in manners and morals. In such surroundings it was easy to acquire the habit of sustained effort whether or no the task to be done were in itself attractive.

There was, however, abundance of interest, of variety, of intellectual stimulus, of self-expression and self-discipline. In the manse one learned early to distinguish good from evil, to realize the meaning of sin and of righteousness. Control came mainly through the development of the child's own conscience. It was a place where he imbibed lessons of duty, of service, of self-abnegation, by associating with those to whom such virtues were matters of daily practice—were indeed the very essence and purpose of life. I believe I am speaking for Dr. Cairns and his predecessors no less than for myself, when I say that the daily round, the common task, of our fathers and mothers—especially the mothers—laid for us a foundation never to be shaken. From their example even more than from their precept we learned the fear of God which is the beginning of wisdom, and the love of God which is the beginning of religion.

It has been a fashion to disparage things Victorian. Of all Victorian things none was more 'Victorian' than the Scottish manse in the period of my childhood. But I should be sorry for any man who, knowing it for what it was, could make it the subject of a cheap sneer. Let no one picture it as narrow, or severe in its restraints, or provocative of recoil. To me there are none but sunny memories of the Scottish manse—memories of a happy family life, of a genial air, of a warm and sheltered garden that fostered the growth of mind and heart. In these days of revolt from authority, of practical hedonism, of self-seeking, would that we could re-create in every home something of the atmosphere of the old Scottish manse.

My memories go back to a time when the Disruption

was still a fairly recent event in the history of Scotland. My father was one of those who had 'come out' in 1843 —had come out as a young man from the charge of a city parish, bringing his people with him. It had been a time of spiritual revival, and the effects were still apparent in the circle in which my boyhood was spent. The Church had been torn and convulsed, but its sections were more than ever alive. Their welfare, their activities, the utterances of their leaders, were matters of public concern. In those days the Church was a large part of the nation's life. The heat of Disruption fires had abated, but the glow had not faded: men and women were still inspired by the sense of a sacrifice endured for conscience' sake. It had been a very real revival.

But when a revival has been brought about by strife and disruption a heavy price has afterwards to be paid. The stimulus, the efflatus of conflict and renunciation, these depart; the tragedy of separation remains. The saints and heroes of the struggle are taken to their rest; their descendants are left to suffer the weakness of division.

And thus it comes about that as the generations pass and time works his changes, we see more and more clearly that if we would be true to the spirit of our fathers we must in a sense undo their work. We find ourselves faced by a new duty—the duty of healing ancient breaches, of seeking in reunion a recovered strength, a fresh point of departure for the tasks that lie before the Church of Christ.

FROM A SPEECH AT THE UNIVERSITY OF EDINBURGH,
NOVEMBER 2, 1917, ON THE OCCASION OF CONFERRING
THE HONORARY DEGREE OF LL.D. ON HIS EXCELLENCY,
MR. WALTER H. PAGE, U.S. AMBASSADOR

IN asking your Excellency to address us I will say only a few words. Last night you spoke of the ideal of a democratic University as realized in your own country. Coming here you find yourself in a congenial atmosphere : in Scotland you breathe the native air of democratic University education. Our Universities may claim to be the *almae matres* of the Universities of America. But while we boast this community of sentiment, we must admit that in one respect your Universities have gone far beyond ours. I wish you could communicate to us the secret of their success in securing material support, public and private. You drew a picture of a western University to which students of all classes, all ages, and both sexes, flocked in thousands ; where in one room they were reading Sophocles and Plato, and in another they were taught to milk the cow. That last is an art in which your Universities are indeed expert. In the academic pastures of this island, benefactors, for the most part, yield but reluctant drops to our uncertain fingers. . . .

Here you find us a Democracy depleted of its demos. Three years ago our young men went from us to fight for ideals of liberty and righteousness without which democracies are vain. Now yours are pressing forward to join them. We are thankful for that, first, for the sake of the war. Their coming makes the issue speedier, if not more certain. It is an engineers' war, and America is a nation of engineers. And second, for America's sake. To lovers of your country it would have seemed a calamity had she permanently stood aloof. Those who have known the difficulties that held back her rulers

have waited, in patience no less than hope, for the hour when she should take a place worthy of her destinies. . . .

FROM A SPEECH AT THE UNIVERSITY OF EDINBURGH,
MAY 24, 1918, ON THE OCCASION OF CONFERRING THE
HONORARY DEGREE OF LL.D. ON THE PRIME MINISTER,
THE RIGHT HON. DAVID LLOYD GEORGE

THE Prime Minister comes to us garlanded with victory in a recent parliamentary contest. In holding this additional laurel for an instant over his brow, I am only expressing on behalf of the University the confidence in him which we share with the vast majority of the British race. None of us can measure the burden of his present responsibilities. But we know our own need of strong leadership. In the Prime Minister we hail a resolute leader, a representative and spokesman of the nation's unconquerable soul.

Coming to-day to the hill-men of Scotland he may count upon the same response as he would receive from the hill-men of his native Wales. Himself a child of the mountains, he finds in them inspiration and solace. Like an earlier David he lifts his eyes to the hills from whence cometh his help. May I suggest that there are other elements of parallel between the Prime Minister and his great namesake? The earlier David also came to wield the highest authority in the State. He rose by the force of his own character: he became a national hero because he embodied what was most heroic in the genius of the people; because he had courage in adversity and could be generous in success. He knew how to win men's hearts and how to stir their best impulses.

One thinks of that early David as the Hebrew prototype of the Celt—Celtic in fire, Celtic in imagination,

Celtic in charm, and Celtic in his enjoyment of battle. He had a skill that was almost Welsh in playing the harp ; and on the rare occasions when his harping failed of its effect, he had an agility that was almost Welsh in dodging the javelin. He may not have been always too scrupulous about the property of the Church, but he proved himself to be a born Minister of Munitions when he turned even the stones of the brook into weapons of war. Quick in decision, strenuous in action, he was emphatically a believer in the knock-out blow. He did not escape difficulties with his Generals. The sons of Zeruiah, he said, were too hard for him, but he succeeded at last in securing unity of military control. He was perhaps fortunate in having no newspaper press ; but he lives, and will for ever live, in the pages of a severely dispassionate historian. From that obviously uncensored narrative we learn that the earlier David was no plaster saint. He was full-blooded and a fighter, whose greatness did not exempt him from mistakes and inconsistencies. But through all his errors he strove nobly, he never lost faith in lofty ideals, he achieved the people's good, and he deserved the people's love. Through many dangers, and after long strife, he brought them in triumph to security and peace. His final injunction to Solomon: 'Be strong and show thyself a man,' epitomized the habit of his life. Sir, that is your motto, as it was his ; it is also your message to the nation in her hour of trial.

AT THE UNIVERSITY OF EDINBURGH ON THE OCCASION
OF CONFERRING THE HONORARY DEGREE OF LL.D. ON
FIELD-MARSHAL SIR DOUGLAS HAIG, K.T., MAY 28, 1919

SIR ALFRED EWING, proposing after luncheon the health of Sir Douglas Haig, said that in the triumphal progress

of the Field-Marshal through other parts of North Britain he had visited several places which claimed to have a share in the honour of his nativity. There was some danger of a tradition growing up which would assign to him as many birthplaces as the late Mr. Gladstone. But Sir Alfred could tell them on the authority of Sir Douglas Haig himself that he was born in one place only, and that was 24 Charlotte Square. Sir Douglas also had a lively recollection of having crossed a few years later to another house in the same Square to begin the process of education which was so happily consummated that day by the award of a suitable Degree. This incident of his debut in scholarship was confirmed by Sir Douglas Haig's earliest teacher, the Rev. Charles Shaw, who to their great pleasure was also now a guest. Mr. Shaw assured him that the young Douglas was a very apt pupil. It appeared that the real 'Happy Warrior' deserved the praise given by Wordsworth to his ideal counterpart

Who with a natural instinct to discern
What knowledge can perform, is diligent to learn.

By virtue of that diligence and instinct Sir Douglas justified a recent description, that he was the best educated soldier in the Army.

It was fitting that the Universities should do him honour, he had led so many of their sons. He led them from defeat to victory: he led them when his back and theirs were to the wall. He led them to the final triumph of those impulses of decent conduct and decent thinking of which the Universities were in some sense the special guardians. Honours were now falling upon him from Universities and Corporations like showers of manna. Perhaps it would be more appropriate to compare them to an intensive bombardment. Sir Douglas must often wish that his admirers would find their ammunition

spent. When the Field-Marshal opened his morning post-bag and drew out offers of the Freedom from two or three more cities, and Degrees from two or three more Universities, he must be tempted to exclaim, 'If this be freedom, give me again the servitude of high command; if these be Degrees, restore to me the joyous irresponsibility of the undergraduate!'

But in the present temper of his fellows this would be a vain prayer. And why? For many reasons, but most of all because he embodied in his own person what they regarded as the finest features of the national character. He was the apotheosis of their best selves. Their hearts warmed to him and their blood surged when they thought not only of what he had done but what he was. To Scotsmen especially he was the epitome, the composite presentation, of all that had made Scotland great and kept her more or less lovable.

One of his characteristics could not be passed over without mention—the spirit of self-abnegation that guided him in the matter of unity of military command. Never surely did a man prove himself worthy of the first place so clearly as he did by taking the second. And if they were grateful to Sir Douglas for many things he had done and said, they were also grateful for things he had not said. He had not joined the band of eminent Statesmen and Admirals and Generals, who, having done great things in war, hastened to explain them in what was called peace. His countrymen looked for no apologia from Sir Douglas Haig, and he had no temptation to make one, for he had nothing to explain away. They drank to him in admiration, affection, and undying gratitude.

BIOGRAPHIES FOR BEGINNERS

IRREGULAR LINES ON TWO DISTINGUISHED GUESTS
EDINBURGH ROYAL SOCIETY CLUB, DECEMBER 21, 1925

Their names
and meritorious qualities.

THOMSON, Sir J. J.
And Lord Balfour, formerly A. J.
Had the good fortune to inherit
Powers that gained for them the Order of Merit.

One laid the foundations of modern physics.

Using brain more than muscle
Thomson discovered the electron (late ' corpuscle ')
He demonstrated the simplicity
Of matter's being built of electricity,
And exceeded our most sanguine hopes
By separating isotopes.

Of the other,
Honi soit qui mal y pense.

A somewhat earlier starter,
Balfour wears the Garter ;
After taking charge of Parties and Affairs
He gives himself no airs,
And has won his countrymen's affection
Irrespective of political complexion.
Ireland, to boot,
Simply loves him, for he did not hesitate to shoot.

His doubt
when told
that Balfour
must go.

There was nothing sinister
When, as Prime-Minister,
He stuck to his task with
A tenacity that annoyed Mr. Asquith.
Inept I call
It to dub him sceptical
Though he may have felt the shadow of a philosophic doubt
When deciding which were better—to be in or out.

How strange that metaphysics, now, and physics,
Ired of asking whether half a dozen *is* six,
Have been interchanged among the many labours
Of my illustrious neighbours.

For the Master of Trinity
Is reported to have taken up divinity :

Averting his gaze
From atoms and rays,
He puts clean out sight
The behaviour of light,
And professes not to want a
Word more about quanta.

He cites, for apology,
An invitation to discourse about Theology !

It is
rumoured
that
Thomson has
become a
Gifford
Lecturer.

And the owner of Whittingehame
Has conspicuously made a hit in jam
Through the work of his Board
In showing how fruit should be stored.
'Twould be a thousand pities
Had he not a Council and committees
To command from his perch
At the Department of Scientific and
Industrial Research.

The Lord
President of
Council is
officially
responsible
for research
and indulges
in Food In-
vestigation.

In Fellows
Whom age only mellows
Such unstaleable variety
Takes the fancy of our ancient Royal Society.

Their
welcome by
the Royal
Society Club

So here we toast them, feeling no satiety
Nor trace of inebriety,
For, though Horace says that *dulce est desipere*
In loco, we might find the streets are slippery.

Is warm but
judicious.

XIII

THE LATE LORD BALFOUR

FROM *NATURE*, MARCH 29, 1930

I HAVE been asked to write a note about Lord Balfour's association with Universities, perhaps because I served under him as Vice-Chancellor in one of them for thirteen years. Perhaps also because a previous service under him at the Admiralty, when he was First Lord during the war, had created a personal link which the subsequent intercourse maintained and strengthened. Meeting Lord Balfour from time to time in the serene yet vigorous evening of his life, one found in him continually more and more to admire and revere and love.

Lord Balfour's connection with Universities is too big a subject for a brief note. He was Chancellor of two—Edinburgh for thirty-nine years and Cambridge for eleven. He was Honorary Doctor of at least sixteen, Rector of two, a Member of the Senate of another. He had been Gifford Lecturer, Romanes Lecturer, and so on. Such points of established contact meant much to the Universities concerned. His immense influence and authority could be invoked ; his advice could be sought ; his sympathetic comprehension of University affairs never failed. It was for such reasons that he undertook, in his double capacity as Chancellor of Cambridge and of Edinburgh, to lay the case for the Universities before the Treasury, thereby securing a much-needed increase in the annual grants.

To Balfour himself the academic atmosphere was con-

genial. He was conspicuously a fine flower of University culture. He understood the ways and aims of Universities, their potentialities, and their difficulties. In many addresses he spoke of them with insight and affection. He praised their past, noting especially how they had served as disinterested pioneers in scientific research. He had confidence in their future. But he was acutely alive to the need of adaptation to altering conditions. He saw that the promotion of research had become a public duty, to be undertaken on a scale larger than they could handle, and needing greater resources. Fortunately, it fell to him, as Lord President of the Council, to direct the development of scientific and industrial research as a national task.

His own membership of Trinity, his brothers' fellowships there, the tenure of the Cavendish Chair (and, later, the Chancellorship) by his brother-in-law, the late Lord Rayleigh, and the appointment of his sister, Mrs. Sidgwick, to be head of Newnham, gave him many ties with Cambridge. When he was asked to become Chancellor, he had already for a long time held the like office at Edinburgh, and it was typical of his courtesy that before accepting the Cambridge invitation he consulted Edinburgh opinion as to whether there might be objection to his holding both. He was quickly reassured, and certainly neither University was prejudiced by his association with the other.

With Edinburgh Balfour had a geographical connection, for his ancestral home was not far off. When in residence at Whittingehame, it was easy for him to come to us. His visits were not infrequent, especially after the claims of political life had grown less insistent. Some occasions were ceremonial, others more private, and these he unaffectedly enjoyed. I recall his presiding, in December 1924, when the Prince of Wales opened a new building

and received an Honorary Degree. The Prince, duly 'capped', was called upon to speak, and to the delight of a vast concourse of undergraduates proceeded thus to chaff the Chancellor :

' This is by no means the first time, Mr. Chancellor, that we have met one another in circumstances such as these. You will doubtless recall a day at Cambridge when you were good enough to confer a degree upon me in Latin, a language with which, I regret to say, I am unable to claim great familiarity. Shortly afterwards I found myself in a position, as Chancellor of the University of Wales, to retaliate, when in admitting you to a degree at Cardiff it fell to my lot to address you at some length in Welsh. Now, for the third time, with no handicap on one side or the other, we meet in a common tongue, and the match, if I may put it so, remains all square.'

Another notable occasion was the rectorial address which Mr. Baldwin, then Prime Minister, gave on November 6, 1925. A bad tradition among Scottish students had made the address of the Rector an opportunity for a 'rag'. In pre-war days the Chancellor had suffered from this exuberance to an extent that strained even his good-nature. When I asked him to come he stipulated that this time there should be reasonable order. Accordingly I summoned the leaders of the students' Unionist, Liberal, and Labour associations, the president of the Athletic Club, and one or two more, and showed them Lord Balfour's letter. They declared with one voice that in his presence order must be and would be kept. Sinking political differences they wrote a round robin begging him to trust them and come. He did, and was gratified to find them as good as their word. The suppressive measures were their own ; if drastic, they were completely successful. It was the dawn of a new era.

An example of a less formal visit was when Balfour came, in January 1927, to talk to the students of history about the London Conference on Imperial Relations, and deftly countered an invited fire of questions. Another was when he presided at the first of Professor Eddington's Gifford Lectures. Such contacts were, I think, as agreeable to him as to us. His greatness, his maturity, his detachment from the commonplace, were no bar to intercourse. He would charm those he met into giving him of their best. To some he would talk philosophy, to others music, to others medicine, to others the bewildering developments of modern physics. There his bent towards science as well as philosophy found a double interest. He rejoiced in the escape of scientific thought from the crude materialism which was vocal fifty years ago. He followed the kaleidoscopic changes of atomic theory with an alertness that was the envy of younger men.

My last meeting with him has left a happy memory. It was on the day in July 1928 when, in honour of his eightieth birthday, he was entertained by the British Academy. At the luncheon he had been in great form, clearly delighted with the tribute and moved by it. That summer evening I met him again, sauntering hatless near his house, genial, buoyant, radiant. It was hard to believe he had eighty years behind him. Those whom the gods love die young : of that company was Balfour.

XIV

SCIENCE AND SOME MODERN PROBLEMS

A HIBBERT LECTURE AT CAMBRIDGE, FEBRUARY 17, 1933

I

IT happens that on two recent occasions the duty has fallen to me of reviewing the progress of physical science and its practical applications during a century which has witnessed immense scientific developments, and has, in consequence, undergone an immense social change. No living memory can do justice to such a theme, but an old scientific worker finds some compensation for his conscious antiquity in the fact that he can look back, as a matter of personal experience, over changes which to younger men are subjects only of history or legend. He has himself seen the small beginnings of things that have grown great, he has been thrilled with the strangeness of novelties that are become familiar, and he has shared in some degree the hopes and the efforts, the delights and the disappointments of the early pioneers.

It was in that spirit that I delivered an official lecture entitled 'A Century of Inventions' when the Institution of Civil Engineers celebrated the centenary of its Charter. In that spirit too I addressed the British Association as President of the York Meeting last year, when they were entering on the second century of their comprehensive endeavour to promote the advancement of science.

On such an occasion it is natural and proper to dwell

SCIENCE AND SOME MODERN PROBLEMS

on the greatness of the achievements and their value to mankind. We trace in the century's progress a progressive enrichment of human life. Discovery and invention have scattered a largesse of actual and potential benefits. From science there has come a flow of material bounty outside man's previous experience and his wildest dreams, not only meeting recognized needs but providing toys and joys to which he had never aspired. I need not dwell on this aspect of what science has effected ; its gifts are accepted commonplaces. If you would estimate these benefits aright, think of what you would lose were you to go back to the conditions of a hundred years ago ; think of the comforts, the interests, the securities to health, the conveniences personal and communal, of which you would be deprived. Whatever criticism we may justly pass on modern life, this much is certain—we have no wish to set the clock of invention back a hundred years.

Nor indeed could we set it back if we would, by however small a space of time. And I shall go further and assert that the procession of invention and discovery cannot be stayed : it inevitably sweeps on to further conquest. Could we look into the future we should discern the everyday working of wonders not yet known or imagined which will then be part and parcel of a still more complex life, a life that is bound to grow richer than ever in the cumulative endowment which science will continue to pile up.

There is no possibility of returning to a more primitive state, nor even of checking the steady advance. We do well to bear this in mind when we come to consider the other side of the picture—the drawbacks and the dangers which follow this procession of discovery. I used, as a young man, to rejoice whole-heartedly in the procession ; indeed, for a long time, the benefits

seemed so obvious, so desirable, that one then thought of nothing else. But now we are compelled to qualify our enthusiasm. We see, only too clearly, that the gifts of science are not without alloy: that they have brought with them social difficulties which tend to become acute. It is of some of the modern problems directly resulting from scientific progress that I would speak to-night.

They are modern problems because the mechanical age, which has given rise to them, is itself of modern birth. You have only to look back a little more than a century to find mankind beginning to emerge from a state which, in respect of scientific devices, had been substantially unchanged for hundreds of years. The Industrial Revolution had its germ in the invention of the steam engine by James Watt towards the end of the eighteenth century. Up to that time man's *power*, in the mechanical sense, had been almost wholly limited to what his own muscles would yield. Except for such help as he got from domestic animals, from the water-power of a few streams, and from the wind, especially as a driver of ships, his toil was in the sweat of his own brow. But steam, as an agent for creating power on a large scale through the burning of fuel, was a new and potent slave—a giant slave which could multiply his own effort a thousandfold—a slave, too, that would never tire. This made it possible to drive machines which would do the work of many men and accomplish tasks such as no man or combination of men could attempt. In due time the spinstress whose wheel had twisted an individual thread with personal—almost affectionate—care, became the spinning-frame tender, herself supplying all the little labour which thousands of threads, spun incredibly faster, but with no less precision, might require. And so it was in almost every craft of man. More and more does

he hand over his labour to the mechanical slave, thereby effecting an enormous increase in the proportion of the output to his own effort. The slave takes many forms, and from them come a multitude of other sorts of things, which man's personal labour never produced at all.

That is what we mean by the Industrial Revolution. The phrase is appropriate, for the process has meant an upsetting not only of industrial habits, but of social relations and economic ideas. And now it has become a world-wide revolution, with effects as drastic on mankind at large as the overthrow of principalities and powers.

At first it was local. It began, as we all know, in Great Britain, drawing workers from the fields to the factories, creating a new demand for labour, quickly adding to the population, establishing new social types, both of employer and employed. Raw materials poured into our island and manufactured goods poured out. The value of the exports paid, most conveniently, for the import not only of materials for manufacture, but of food-stuffs for the rapidly increasing number of mouths. For a time Britain was in effect the workshop of the world. But those halcyon days, if you call them so, could not last. Other countries soon learnt the trick of manufacture, and now there is none, not even the most backward, that does not know it. Competition spread from Europe and America to the East. Japan, India, China, which once were ready markets for our goods, are so largely mechanized as to be among our rivals. The supremacy of Britain as an industrial hive has gone, never to return.

But it is not my business to-night to consider this matter from a national point of view. We have to look at its wider aspect, as a world phenomenon, as a factor in the general life of mankind. We are confronted with it on all sides as a factor of tremendous import, in the

extent to which it may affect the burden and satisfy the material desires of man.

The first characteristic of the mechanical age was that it supplied man with power, the kind of power which engineers—in recollection of a once very useful auxiliary—still measure in horse-power. That is the unit which Watt himself employed to specify the performance of his engines. And now we have power generated on an enormous scale in central stations by turbines that develop hundreds of thousands of horse-power. It is distributed everywhere, through the invisible vehicle of the electric current, to light our houses and drive our workshops and our tram-cars, and the whole process is so nearly automatic, even in the generating stations themselves, as to escape almost entirely the bodily labour of man. Our ships, too, are big generating stations, and many of them have learnt to dispense with heavy labour in the working of the ship and the feeding of the furnaces.

It is not only in respect of power that the machine takes the place of man. The machine has become an automatic craftsman ; it turns out manufactured articles with a swiftness and precision that the most skilful workman cannot rival. Here we have a second reason why it has effected a social revolution. Power is one of the secrets of its influence : the other is what we may call its automatic skill—the skill that has been put into it by the ingenuity of its inventor and the accuracy of its constructor. Between them these creators of the machine have enabled it to repeat with meticulous exactness a prescribed operation in which mechanism acts as a substitute not only for manual force but for intelligence. You have a simple example when you take a ticket for the 'Tube' railway. You drop your one or two or three pennies into an orifice, from which they pass to actuate a group of wheels and levers, and the machine delivers

your ticket with the promptness and care of a conscientious booking-clerk. Here there is no question of ' power-production ': it is the gravity of the descending pennies that supplies all the driving energy the machine requires. But I wonder how many booking-clerks have lost their actual or potential jobs through the labour-displacing potency of this now familiar device. Or take another instance which has equally little to do with any large-scale use of power. In the packing of cigarettes into their boxes it is considered important that the printed side should be uppermost. To place them so used to be the work of deft female fingers, not, I imagine, very highly paid. Nevertheless a machine now serves to eliminate even that item of cost. The cigarette is automatically revolved, and when the print comes uppermost a photoelectric cell (which is one of the notorious mysteries of physics) observes the fact—if I may apply such a phrase to a wholly unconscious agent—and seizes that moment to drop the cigarette into its place. Here again, as in so many instances of greater economic consequence, labour-saving means labour-displacing, through the substitution of the machine for the human eye and hand.

In the early stages of the Industrial Revolution that fact was masked by the rapid increase of output which rose to meet an apparently insatiable demand. The world was the buyer : the machine could supply products which it wanted at a price it was very willing to pay. But now, when makers have to struggle for a footing in a competition for limited and guarded markets, when production shrinks and prices are cut to the bone, more than ever does the machine take the place of the wage-earner, and its triumphs—if one may call them that—are measured by the augmented output for each worker who can still find employment as its minister.

The past fifteen years of peace have seen a notable

development in the labour-displacing function of the machine. In part this is an outcome of the war: the intense demand for munitions, coming at a time when labour was excessively scanty, had compelled a resort to mechanism. Products such as shells and fuses required an exactness which ruled out the tolerance that had been usual in older methods of manufacture. Hence the supply of munitions was pushed on lines that made production rapid, voluminous, and uniform. Precision, controlled by mechanical gauges, became automatic and inevitable. The machine, which did not make mistakes and could be multiplied at will, came into its own—conquering a kingdom which it now holds in the peaceful avocations of post-war industry. Indeed, it is a characteristic of that industry that the kingdom of the machine continues to expand. More and more does the manufacturer seek to escape what are called labour troubles by substituting for the caprices of human fingers and human sensibilities the impassive exactitude of the machine. And he has the strongest possible motive for making the output of the machine as large as possible, for the larger the output the lower is the price at which the articles it produces may be offered for sale, since the price they fetch must cover over-all charges such as a due share of rent or interest on the value of the machine itself with its housing and retinue. Historically considered, that rent or interest is a payment for work done upon the machine before it could begin to function.

I need not dwell on points that are obvious and familiar, nor need I weary you by quoting figures. What I would have you note is that this cheap mass-production of goods of all sorts is a modern feature of industrial life and is now rapidly advancing to a position of dominance through the increasing perfection with which mechanism is constructed to take the place of hand and brain. It is capable of yielding an output far more lavish than

hand and brain could ever yield. The economic consequences are twofold :

In the first place human labour tends increasingly to lose employment.

In the second place there is an actual or potential production of commodities much more adequate than it was in the past to satisfy the material desires of man.

These two facts together present us with the shocking paradox which society has still to solve : that in the midst of offered plenty we are surrounded by poverty and want. It is distribution, not production, that is at fault. The machine stands there, often idle, indeed, but always ready, and capable of turning out in ample measure the usable forms of wealth men need. But its activity is determined by the demand for what it can produce, and that in turn is determined by the purchasing power of those who would buy. The whole industrial process, in any field of manufacture, has its parallel and its symbol in the automatic ticket-supplier of the Tube. There, if you will, is a typical machine. It acts only when pennies are dropped into the slot. To a customer without a penny, however great his need, it makes no response. And in its own small way it has done its damnedest (as people say nowadays) to swell the number of the penniless, or nearly penniless—certainly the wageless—unemployed.

Here, then, we have a social problem of really desperate urgency.

Do not think of unemployment as local : it is almost world-wide. Do not think of it as temporary, as a thing which will pass when trade improves. Trade, indeed, has its fluctuations, its booms and its slumps ; the pendulum swings, the waves have crests as well as troughs. At the moment we are in a hollow of the wave. That has intensified the trouble but did not create it. Its

origin is confused and its extent is aggravated by causes which may disappear. Their disappearance may afford a temporary relief, but the root cause will remain. It will not only persist ; it will steadily grow. Unemployment is a cancer which no palliative medicine can cure. For unemployment springs, essentially, from the inevitable advance of applied science, which year by year increases the efficacy of the automaton, enlarges the range of its activity, and improves its quasi-skill, so that more and more it supersedes the craftsmanship and even the unskilled labour of man. Through all the ups and downs of industry that process will go on. This is the greatest economic problem of the time, greater and more far-reaching than any questions of currency or war debts or tariffs or reparations, important though these are.

To solve this problem is a task which no machine—no organ of second-hand thought—can ever accomplish. It will need the best brains of man and his highest exercise of them, his widest sympathies, his finest moral instincts, if it is to be solved aright. To that task he must set himself, realizing how new and strange are the issues it presents, how it calls for a sanity and mental freshness that can divest itself of cherished preconceptions. To an old man like myself it seems insoluble save perhaps by turning into untrodden and uncharted ways, where more adventurous feet must lead. How, with abundance within reach, are we to effect distribution ? How are we to equate effort and reward ? How are we to satisfy, fairly, the material needs of man without damage to his soul ? How are we to encourage the eternal virtues—industry, thrift, self-denial ? Questions crowd in : I cannot attempt an answer. And yet, if society is to save itself, they must be met.

This much seems clear, that on any equitable system the worker—and in that Utopia we shall all in some

sense be workers—will command more leisure than was formerly his lot. I tie myself to no estimate of days and hours, but it stands to reason that the task of controlling our mechanical slaves will take up much less of our time and energy than would be needed to do the work ourselves. We shall be like the (perhaps ideal) modern housemaid, who after half an hour of her Hoover—I do not mean the retiring President—may sit with her feet on the fender. By some of us such leisure will be well employed ; but not, I fear, by all. To most men, I believe, the obligation of toil is a blessing in disguise. It is true that when one looks back to the early stages of the Industrial Revolution, one is horrified to see a blot on the civilization of the time. There were cruel years when childhood suffered and was stunted in the factories, confined through the endless hours of an intolerable day. We are thankful that these times are past ; but now the very agent which wrought that mischief—the machine—threatens us with an exactly opposite evil, by depriving us of the blessed drudgery which helps to give man pride in his usefulness, and, incidentally, delivers him from much temptation. It may well be doubted whether the extended leisure that is now in sight will make him happier, or wiser, or better. To spend it to good purpose, to escape or to mitigate boredom, will be one of the problems for a leisured plebs. Many people will not find *panem et circenses* an adequate prescription, though the circuses include scientific products like the talkies and the dogs and the tote. As an old educator I doubt whether even education will prove itself the universal panacea some of its friends seem to anticipate.

The influence of the machine in producing unemployment is, as I have said, a world problem. No country escapes it save perhaps Russia, which stands alone, and there the cure, as many think, is worse than the disease.

Attempts to foster a nation's self-sufficiency in manufactures by the erection of tariff walls provide no remedy ; indeed they aggravate the evil by adding fresh provinces to the kingdom of the machine. To discuss the problem of unemployment from the point of view of a sectional nationalism would be useless and misleading : here, as well as in other fields, we are coming to recognize that a quasi-patriotic selfishness is futile, that the advantage of each is attained by studying to promote the benefit of all : that the world as a whole must find salvation if any of the nations is to be secure.

II

And now we come to the second main problem into which the progress of science has plunged us, namely, the burden of armaments and the menace of war. Here, too, there is urgent need that we should learn to think internationally. To say so is a truism : it is only by dropping mutual mistrust that the burden may be lightened, the menace averted, and the tragedy of war escaped.

To one who had pursued science and the applications of science with ardour from his youth ; finding in it an object worthy of affection, of enthusiasm, of whatever powers he had with which to serve it, there was much sadness of disillusionment in the Great War. For one realized then, as never before, that discoveries whose benefit to man had seemed beyond dispute could be prostituted to ignoble use, could be made instruments of hatred and of hurt, could be deliberately perverted to work his destruction ; and that, too, on a colossal scale and with an indiscriminate malignity which exceeded the worst excesses of primitive times. It was a shock to discover that the fertilizing stream could so easily become a ruthless torrent ; to be made aware, almost

suddenly, of what I have called in another place the moral failure of applied mechanics. Had the world suddenly gone mad? Was I wrong to imagine that the sweet reasonableness of science had in it an ethical quality which should have saved its gifts from so horrible an abuse? I think now that I was wrong. Man had laboriously, through centuries of aspiring toil, built up a temple of civilization in which some of the coping stones had been chiselled and placed by the engineer; was it now to bring ruin on those who trusted it for shelter? The work of building that temple had been shared, conspicuously and honourably shared, by the very men who seemed now eager to destroy us, whom we—however reluctantly—now set out with grim determination to destroy. Between the scientific men of England and Germany there had been, so we felt, a true community of aim, a friendly rivalry in research, many links of mutual admiration and acceptance of common leadership. And yet in 1914 we sprang into hostile camps, turning our joint achievements as physicists, chemists, or engineers into weapons of unexampled ferocity. For four years we strove, more and more bitterly, seeking on both sides to bend the resources of science to the task of exhausting the adversary. The damage to both sides was appalling: as the war went on it was accepted as inevitable. Each side saw itself approach exhaustion: its chief concern was whether it could endure until the other should collapse. The exhaustion from which both sides suffered was not simply an exhaustion of the fighting men, but of the whole civil population behind them. That gave the war a character which other wars had not known. It is no exaggeration to say that the war inflicted on civilization an almost mortal wound, a wound which even now is far from healed. Looking back, we see that there was much faulty surgery in the Treaty of Versailles, in its

impossible reparations, in its pandering to the selfish follies of a narrow nationalism. But no surgery, however wise and skilful, could have quickly healed so grave a wound.

For our present purpose there is no need to ask who was to blame in the beginning of the war. You may think, as I thought and still think, that one side was definitely the aggressor; that Britain took up arms only as a stern duty, in response to a clear call of conscience which sanctified the act. Or you may distribute the responsibility with an impartial hand, guided—shall we say—by completer knowledge, or perhaps completer ignorance. Whatever your verdict, the fact remains that the war happened—an orgy of world madness which perverted to the purposes of savagery the fine fruits of man's long study of nature, and the most subtle products of his trained ingenuity.

Has that ghastly experience made the world wiser, or is there worse to come? Was the Great War but one act of a cumulative tragedy, where the curtain is ultimately to fall on the fragments of a shattered society, on the death of what has seemed to make human progress worthy of our efforts and our hopes?

It is in no spirit of speculation or pessimism that one asks this question. What every thinking man ought to realize is the gravity of the menace that another great war would involve. The destructive possibilities of science were being continuously exploited and intensified during those four years of struggle. They are being intensified still. Even the preparation which had been made for continuing the war into a fifth year went far beyond anything previously in use. On that point let me quote the words of one who speaks with an authority to which I can lay no claim. Mr. Winston Churchill has a vivid pen, and here he is describing facts which came

within his official knowledge. I would have you give them the serious attention they deserve :¹

' All that happened in the four years of the Great War was only a prelude to what was preparing for the fifth year. The campaign of the year 1919 would have witnessed an immense accession to the power of destruction. Had the Germans retained the morale to make good their retreat to the Rhine, they would have been assaulted in the summer of 1919 with forces and by methods incomparably more prodigious than any yet employed. Thousands of aeroplanes would have shattered their cities. Scores of thousands of cannon would have blasted their front. Arrangements were being made to carry simultaneously a quarter of a million men, together with all their requirements, continuously forward across country in mechanical vehicles moving ten or fifteen miles each day. Poison gases of incredible malignity, against which only a recent mask (which the Germans could not obtain in time) was proof, would have stifled all resistance and paralysed all life on the hostile front subjected to attack. No doubt the Germans too had their plans. But the hour of wrath had passed. The signal of relief was given, and the horrors of 1919 remain buried in the archives of the great antagonists.'

And of more recent developments he remarks :

' The campaign of 1919 was never fought ; but its ideas go marching along. In every army they are being explored, elaborated, refined under the surface of peace ; and should war come again to the world it is not with the weapons and agencies prepared for 1919 that it will be fought, but with developments and extensions of them which will be incomparably more formidable and fatal.'

' We have entered,' he continues, ' upon that period of exhaustion which has been described as peace. . . . Certain sombre facts emerge solid, inexorable, like the

¹ Churchill, *Thoughts and Adventures*, p. 247.

shapes of mountains from driving mist. It is established that henceforward whole populations will take part in war, all doing their utmost, all subjected to the fury of the enemy. . . . It is probable, nay certain, that among the means which will next time be at their disposal will be agencies and processes of destruction wholesale, unlimited, and perhaps, once launched, uncontrollable. Mankind has never been in this position before. Without having improved appreciably in virtue or enjoying wiser guidance, it has got into its hands for the first time the tools by which it can unfailingly accomplish its own extermination.'

No one can contend that there is any overstatement in the solemn warning which these words convey. Let it be clearly understood that in the warfare of the future, unless some control can be established through a quickening of public conscience, there will be no distinction of non-combatants, there will be no possible defence against the devastation of cities and the almost instant blotting out of those who inhabit them.

In the terrible developments of modern war this characteristic holds, that the power of attack utterly surpasses the power of defence. Notably is this true in respect of aerial warfare. The Victorian poet, with a wonderful prescience of developments that came many years later, describes how in imagination he

Saw the heavens fill with commerce, argosies of
magic sails,

and how he also

! Heard the heavens fill with shouting, and there
rain'd a ghastly dew
From the nations' airy navies, grappling in the
central blue.

A ghastly dew indeed, ghastlier even than that which the poet had in mind. What drops from aircraft is a

cause of slaughter, not its consequence. For the airy navies do not grapple : here and there an attacker may be shot down, but in general he evades such defence as may be attempted, slipping past unchecked to let fall the bombs which carry death.

Here again I will refer you to a more authoritative voice than mine. Mr. Baldwin, who is no alarmist nor given to exaggerate, made a speech in Parliament last November, the night before we celebrated the Armistice, which contained warnings too grave to be ignored. He spoke of the appalling speed of attack which the air has brought into modern warfare ; he told the man in the street that there is no power that can protect him from being bombed ; that the bomber 'will always get through'. He quoted the phrase of a great airman—that it would have been better for the world if man had never learnt to fly. He spoke of the difficulties of securing international agreement, of his doubt that any form of prohibition would be effective in the stress of actual war. With a frankness which seems to have startled the House he used these words :

'I confess that the more I have studied this question the more depressed I have been at the perfectly futile attempts which have been made to deal with this problem. The amount of time that has been wasted at Geneva in discussing questions such as reduction of the size of aeroplanes, the prohibition of bombing of the civil population . . . has really reduced me to despair. . . . If a man has a potential weapon and has his back to the wall, he will use that weapon whatever it is and whatever undertaking he has given about it. Experience has shown that the stern test of war will break down all conventions.'

Against such perils we have but a frail defence in any disarmament conferences, any peace pacts, or even in the League of Nations. And yet, frail though such a defence

is, we must cling to it, we must give our souls to strengthen and foster it ; we must try to make it worthy of our faith. Mr. Churchill is no visionary idealist, but we find him saying this :¹

' It is through the League of Nations alone that the path to safety and salvation can be found. To reinforce it and bring it into vital and practical relation with actual world-politics by sincere agreements and understanding between the great Powers, between the leading races, should be the first aim of all who wish to spare their children torments and disasters compared with which those we have suffered will be but a pale preliminary.'

Speaking for myself, though I claim in this no special knowledge, there does seem among the present clouds and darkness some faint indication of a dawn. It is much that the danger is coming to be widely realized. We are digesting, we have in some degree digested, the unpalatable lessons of the war. War has lost for us whatever glamour of romance it had before we saw the monster face to face. We have learnt to loathe it : every sane man has turned pacifist at heart. And, after all, humanity has a conscience, often dormant, but not incapable of being stirred. Among the scientific possibilities of warfare there are some that have not been invoked, because they were felt to be too revolting to the moral sense. There is bacterial attack—the destruction of an enemy by the deliberate dissemination of disease. Though that has been suggested, and though it would probably not be very difficult of application, it has, so far as I know, not been actually employed—certainly not with recognition or on any important scale. Man's moral sense has shrunk from engaging as his ally what is felt to be a common enemy, dreaded and resisted by every unit of

¹ Churchill, *loc. cit.*, p. 252.

the human race. May we not hope for an awakening of public conscience such as would effectively proscribe other usages which the nations have tolerated but of which they are at heart ashamed? Indiscriminate bombing from aircraft, the use of poison gas, the submarine—may not society bestir itself sufficiently to put such devices outside the pale? The self-protective motive is a strong one, but apart from that, is it too much to ask that the consensus of the civilized world should draw a line, such that any combatant who dares to cross it would incur universal condemnation and disgrace?

The submarine, which I class among those instruments that the conscience of humanity ought to proscribe, is also a child of scientific discovery. As with aircraft, it is compact of the devices of the inventor. Under the stress of war his guidance brought it to something like mechanical perfection. Do people even now realize the stealth and effectiveness of its assassin-like attack? Have they a right estimate of the abuse to which this product of science may be put—the abuse to which in fact it was put during the last years of conflict, when the enemy resorted to what they called unrestricted submarine war? That meant the attacking and sinking, without warning, of any ship, armed or unarmed, hostile or neutral; even hospital-ships were not spared. No attempt was made to save passengers or crew; no chance was allowed them to escape. It was a savage violation of the accepted morals of the sea; it outraged those traditions and instincts of professional conduct which ennable the sailor's calling. The development of such instincts is part of man's social and ethical evolution: to break with them is a reversion to barbarity. The special code of the sailor has been bred in him through all the centuries of his struggle with the sea.

And yet, strangely enough, it was the sailors and the soldiers of Germany who forced the reluctant politicians to adopt the policy of unrestricted submarine war. There was a long contest between the military and the civil rulers, which ended on January 9, 1917, when the Kaiser signed this mandate: 'I order that the unrestricted submarine war be launched with the greatest vigour on the 1st of February.' It was a last card: it is so described in the official documents, and the chief of the Admiralty Staff guaranteed that it would lead to victory.¹ Fortunately for us it failed, though by no great margin. Its menace to civilization persists, unless and until a public sentiment of righteousness is aroused to demand the suppression of all submarine war.

III

It is curious to notice, throughout that controversy, how little the moral aspect of the question seemed to be regarded. The objections that were urged were those of political expediency—the fear of alienating neutral sympathy, and especially the fear of bringing America into the war.

Another noteworthy point in connection with the German submarine attack is this, that when the task of countering it had to be faced, the English politicians and their experts also differed, somewhat sharply. Mr. Churchill has described how, as the monthly tale of sunken tonnage grew more and more alarming, it was only under the pressure of civilian authority that the experts were induced to adopt a system of convoys, by means of which the situation was saved.²

¹ *Official German Documents relating to the World War* (translated under the supervision of the Carnegie Endowment for International Peace), pp. 1116-1277, vol. ii.

² Churchill, *loc. cit.*, pp. 123-138.

On both issues—namely on the policy of attack by Germany, and on the methods of defence by Britain—there was controversy between the politicians and the experts, and it would seem that in both cases the politicians showed the greater wisdom. Politicians are perhaps more completely spared the temptation to be infallible.

We have lately heard much vague talk about a body of doctrine—if that is not too serious a phrase for it—called Technocracy, a name which seems to suggest that the muddled business of ruling the world should be taken out of the hands of statesmen and entrusted to the cleverer fingers of the technical expert. I have seen that urged as a way out of our distresses. We should, I think, pause before exchanging the frying-pan for the fire. It is easy to discover in the politician material for criticism, but I recognize that he should have, and often does have, qualities different from those that make for success in the pursuit of science and its applications. I see no prospect of advantage in taking men from jobs which they do well, jobs that require a special kind of aptitude trained along narrow lines, and turning them instead to tasks that demand a different temper and a wider outlook. It is true that the scientific man's habit in his own subject is to take a dispassionate view, and there are public questions in which that would be of no small service. But he is little likely to be successful in gauging and controlling the emotions of the crowd. I doubt whether an eye accustomed, so to speak, to the microscope is best fitted for a comprehensive survey of international relations, or even for a discerning vision of national affairs.

Most of our time has been taken up by two major problems, the problems broadly of unemployment and of armaments, both created by the advance of science.

Among minor problems arising from the same source is the enlarged power for definite evil-doing which mechanical invention has put into the hands of the miscreant—the gun-man, the gangster, the motor-bandit, and so forth. Significant as such problems are, they are less difficult, for society need not be permanently at a loss in dealing with its own outlaws. The individual who defies it can be compelled into acceptance of the rules, however defective his own social sense.

A more difficult problem is presented by those offences against the community which are committed without criminal intent, as for instance by careless or selfish drivers on the roads, whose consideration for the rights of other people is insufficient to prevent them from becoming a nuisance and a danger. Road 'accidents' now cause a mortality comparable with that due to some of the more fatal diseases. Here, too, the majority may do much by coercing the minority, by setting up standards to which all must conform. It is important to notice that this means some sacrifice of freedom on the part of the innocent, the careful and the well-disposed. For the sake of the common good they give up a liberty which they themselves have not abused, in order that the abuse of it by other people may be prevented.

Here surely is a lesson applicable to international as well as national affairs. For the sake of peace and safety we must be ready to make sacrifices. 'Where there is no vision the people perish,'—that may well be our conclusion when we contemplate the perils by which man is surrounded in the path of his scientific advance.

The advance, as I have said, cannot be checked, nor would we wish to check it if we could. But we must recognize the deplorable fact that man's ethical advance lags far behind. Only by a quickening of his spiritual progress may the perils be escaped. To foster that greatly needed

growth of the soul is an aim demanding all our powers. This is an endeavour in which every man is called to take his part. A public conscience is the sum of private consciences. The vision without which the people perish is a personal vision. The Christian gospel of goodwill—to which the world is so slow to listen—is an individual message. '*Thou* shalt love thy neighbour' is more than a general injunction. It is for each of us, assiduously, hopefully, to seek that which will give light in darkness and guide our feet into the way of peace.

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Printed in Great Britain
by T. and A. CONSTABLE LTD.
at the University Press
Edinburgh

